EXPERIMENTAL INVESTIGATION OF MINIMUM QUANTITY LUBRICATION ON TOOL WEAR IN ALUMINUM ALLOY 6061-T6 USING DIFFERENT CUTTING TOOLS

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I hereby declare that I have checked this report and in my opinion this report is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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I hereby declare that the work in this project report “*Experimental Investigation of Minimum Quantity Lubrication on Tool Wear in Aluminum Alloy 6061-T6 using Different Cutting Tools”* is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not contently submitted in candidate of any other degree.

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Dedicated to my beloved mother Mala, father Muthu, brother Praba,
uncle Bala, aunt Mary, cousins and to all my family, friends and lecturers.

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ABSTRACT

In manufacturing, a great challenge are currently being faced which is competitive marketing place due to manufacturing environment, low costs, aim for high rates of productivity and also with high quality as required by the customers. Aluminum alloys are competitively being used in current industries especially in automotive and aeronautics sector. This study is to experimental investigation of minimum quantity lubricant (MQL) for the end milling machining characteristics towards the tool wear during machining aluminum alloy 6061-T6. The process parameters including the cutting speed, depth of cut and feed rate are selected for study. To develop a model of process optimization based on the response surface method. This experiment was conducted based on central composite design method. Three types of tools used in this experiment which are coated CTP 2235, coated CTP 1235 and uncoated CTW 4615 carbide tool. For every cuts, the tool wear was checked under scanning electron microscope. The tool wear data was then used to make the quadratic models. A number of graphs were plotted to find the connections between input parameter and tool wear. Based on the data generated by multi objective optimization, an optimized tool wear data was made to identify the best inserts and also the compatibility with MQL. It was identified that the insert does not have much tool wear and all of them are in range of below 0.3 mm. Uncoated carbide CTW 4615 was chosen as the best insert at the end of this experiment from the optimized data.

ABSTRAK

Dalam indutri pembuatan, satu cabaran besar sedang dihadapi yang merupakan tempat pemasaran kompetitif berikutan persekitaran industri, kos rendah, cabaran untuk kadar produktiviti yang tinggi dan juga tahap kualiti yang tinggi seperti yang dikehendaki oleh pelanggan. Aloi aluminium yang mencabar kini digunakan dalam industri semasa terutama dalam sektor automotif dan aeronautik. Kajian ini adalah untuk siasatan ujikaji pelincir kuantiti minimum terhadap pemesinan aloi aluminium 6061-T6. Parameter proses termasuk kelajuan memotong, kedalaman pemotongan dan kadar gerakan meja yang dipilih untuk kajian. Untuk membangunkan model pengoptimuman proses berdasarkan kaedah maklum balas permukaan. Eksperimen ini telah dijalankan berdasarkan kaedah reka bentuk komposit pusat. Tiga jenis alat yang digunakan dalam eksperimen ini yang disalut CTP 2235, disalut CTP 1235 dan tidak bersalut CTW 4615 karbida alat. Bagi setiap kerosakan, alat karbida tersebut diperiksa di bawah mikroskop elektron imbasan. Data tersebut kemudiannya digunakan untuk membuat model kuadratik. Beberapa graf telah diplot untuk mencari hubungan antara parameter input dan alat karbida. Berdasarkan data yang dihasilkan melalui pengoptimuman data tersebut diguna untuk mengenal pasti yang nilai terbaik dan juga keserasian dengan MQL. Bersalut karbida CTW 4615 telah dipilih sebagai karbida yang terbaik pada akhir eksperimen ini daripada data yang dioptimumkan.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 CONCLUSIONS AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

mm	millimetre
cm	centimetre
$mm/tooth$	Millimetre per tooth
Ra	Roughness average
$mm/edge$	Millimetre per edge
m/min	Metre per minute
$mm/revolution$	Millimetre per revolution
cm^3/min	Centimetre cubic per minute
µm	micrometre
mg/m^3	Milligram per metre cube
ANN	Artificial Neural Network
RSM	Response Surface Method
MPa	Mega Pascal
GPa	Giga Pascal
J/g-°C	Joule per gram per unit Celsius
W/m-K	Watt per meter per unit Kelvin
mm^3/min	Millimetre cube per minute

LIST OF ABBREVIATIONS

MRR	Material removal rate
CNC	Computer Numerical Control
MMC	Metal Matrix Composite
AA	Aluminum Alloy
MQL	Minimum Quantity Lubricant
Cu	Cooper
Si	Silicon
Mn	Manganese
Mg	Magnesium
Ti	Titanium
Zn	Zinc
OoW	Oil film on water droplet
D.O.C	Depth Of Cut
Expt No.	Experiment Number
RSM	Response Surface Method
ANN	Artificial Neural Network

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Aluminum alloys are trending materials for machining in current world (El-Gallab and Salad, 1998). This is due to its low density (0.33 times density of steel), high fatigue, mass reduction (50% less than grey iron), resistance to corrosion and improved mechanical and chemical properties. According to Frankel and McCreery (2001), aluminum alloys are well known for aerospace industries especially the 2000 series aluminum alloys with high amount of copper. They also stated that a large amount of money being spent for the study of performance improvement and also resistivity towards the corrosion. The use of aluminum base alloy bearings are famous in industrial application especially in internal combustion engines, which needs a good friction and wear resistant material (Liu, 1991).The aluminum alloys are potential to adhere the tool, thus causing built up edge (BUE) and built up layer (BUL) (Broga et al., 2002). According to Cho and Bes (2006), due to improvement in metallurgical and heat treatment process, precipitate were used to improve strength and toughness in alloys, such as Al 2139, which can be applied in military purpose. The aluminum alloy 6061-T6 is one of the popular materials in fabricating thermally stable, high strength and light weighted nanostructure material through large strain deformation (Shankar et al., 2005).

In machining, cutting fluids are important. The large amount of coolant usage contains harmful chemicals both to health of workers engaged in daily machining process and also to the environment (Kalita, 2009). These coolants are expensive in term of recycling and also application. Besides, heavy usage of coolant also does not promise a good lubrication. On the other hand, according to some research, dry grinding caused an excessive friction force between grinding wheel and work piece (Shen et al., 2008). This leads to high temperature in grinding contact area and causes tool wear, poor work piece surface cut and accumulation of chips. Aluminum alloys are competitively being used in current industries especially in automotive and aeronautics sector. The unique property of it, which is light and strong, makes it a good material for production purpose. This study helps to identify the machinability of aluminum alloy 6061-T6. This research is mainly intended to machine the aluminum alloy 6061-T6 under minimum quantity lubricant. Besides, the urges to use MQL in industries are increasing. This is due to the bad effect of flooded coolant towards the environment and human health. According to Boswell and Islam, (2012), the challenge of MQL usage is to dissipate the heat from the tool and work piece in order to ensure the dimensional integrity.

Response parameter such as surface quality is an important parameter especially when producing parts like airfoil in order to reduce the friction (Fuh and Wu, 1995). There are several ways to find the optimized parameter values before machining. Kadirgama et al. (2008) found the optimized value by using response surface method (RSM) and radian basis function network (RBFN). They also mentioned that surface roughness is significant as rough surfaces wear much faster due to the irregularities in the surface which might form nucleation sites for crack and corrosion.

1.2 PROBLEM STATEMENT

A great challenge is currently being faced which is competitive marketing place due to manufacturing environment, low costs, aim for high rates of productivity and also requirement for high quality by the customers. According to Kadirgama et al. (2011), the important characteristics of tool wear are cracking, flank wear, catastrophic, notching, chipping, plastic lowering and the cutting edge and so on. Broga et al. (2002) mentioned that aluminum alloys are potential to adhere the tool, thus causing built up edge and built up layer. Certain process is very significant such as finishing process should be in given dimension, surface finish, type of surface generations, tolerances, and other behaviours (Yahya, 2007). The accuracy of work piece dimension, surface finish, tool wear and tool life towards material removal rate and cutting tool have increased for enhancing the product performance in relation to the impact of environment (Ulutan and Ozel, 2011). The machinability characteristics could be improved if a proper amount of lubricant is applied during machining (Sreejith, 2008). According to Kalita (2009), MQL in high energy machining might not be suitable due to the high temperature and thermal spread over longer time at machining surface. Keeping in mind about this constrains and problems, this study is conducted by considering all the important parameters such as spindle speed, feed rate, tool wear, surface roughness, material removal rate and depth of cut. Besides, a mathematical model are presented to find a combination of independent variables of CNC end milling process to achieve a good result.

1.3 OBJECTIVES OF STUDY

The objectives of this study are as follows:

1) To investigate the end milling machining characteristics towards the tool wear.
2) To develop a model of process optimization based on the response surface method.
3) To evaluate the progression of tool wear due to the usage of minimum quantity lubricant compared to the flooded coolant.

1.4 SCOPE OF STUDY

This study is related to machining of aluminum alloy 6061-T6 under different conditions. The machining type was chosen end milling. The process parameters including the cutting speed, depth of cut and feed rate are selected for study. Since this study includes minimum quantity lubrication (MQL), the amount of MQL will be varied. Three types of tools will be used in this experiment which are coated carbide CTP 2235, coated carbide CTP 1235 and uncoated carbide CTW 4615 tool. The cutting is made with flooded condition and MQL condition for the purpose of comparison. The diameter of tool holder is 10 mm. This experiment was conducted based on central composite design (CCD) method. After each cut, the tool condition are brought for tool wear inspection under the optical video measuring system and scanning electron microscope. The chips will be collected after every cut. The surface roughness will be measured and recorded for further analysis.

1.5 ORGANIZATION OF THESIS

This report was prepared with sufficient information based on theories, observation, facts, procedures and argument. 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 modelling 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 on research studies such as response surface method which are related to the mathematical modelling. 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 elaborated 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 identifying proper parameters involved in 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

Kalpakjian and Schmid (2006) states that milling includes a high performed machining operation by using milling cutter in different types of configuration. Milling cutter is multi-tooth tool that cuts the workpiece and produces a number of chip in a revolution. End milling is one of the common machining operation due to its capability of producing different profiles and curved surfaces. Cutter used in end milling is known as end mill. It is either straight shank for small size or tapered shank for large cutters and is mounted into the spindle of milling machine. The cutter usually spins on an axis perpendicular to the workpiece surface which is mounted on the work table. This cutter can be tilted for the purpose of machine tapered or curved surfaces. End milling is useful in producing variety of surface at any depths such as curved, stepped and pocketed. End mills usually are made of high speed cutting steel or from carbide inserts. The typical dimensional tolerances of the end mills used are in between 0.13 mm to 0.25 mm (Kalpakjian and Schmid, 2006).This type of machining must be handled with care and there are certain guidelines for a proper handling of this machine such as stated follows:

a) Standard milling cutters are preferable and costly ones should be avoided.
b) Internal cavities and pockets with sharp edges must be avoided due to the difficulty of milling them. If possible, corner radius should match the milling cutter geometry.
c) Clamping of workpieces must be rigid to avoid deflection and unwanted results in the end of machining. This rule also applies to the tool holders and other fixtures.

Understanding the machine is one of the criteria in machining. The common type of machining tool used column-and-knee type machines and vertical type is typically found in end milling. But in this study, a vertical computer numerical-control machine is used as shown in Figure 2.1. The typical vertical end milling used in machining is shown in Figure 2.2.

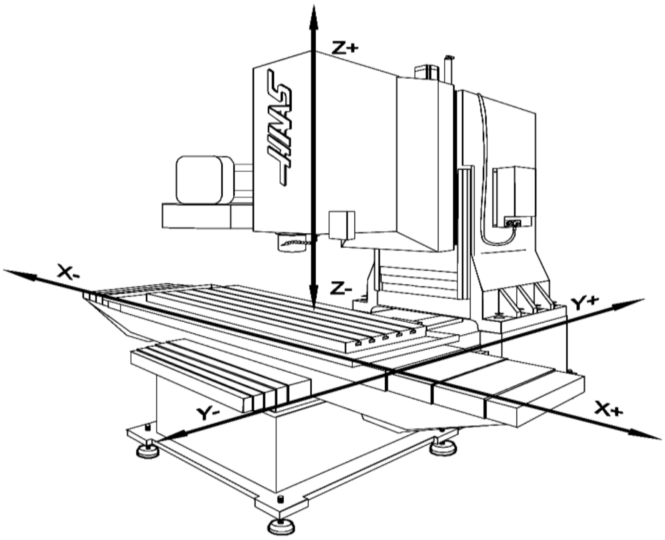


Figure 2.1: CNC vertical type end milling machine.

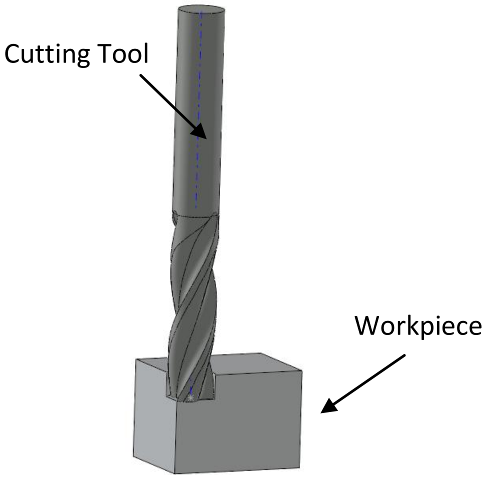


Figure 2.2: Vertical end milling.

A number of machining types were compared and reviewed that milling relative cost for machinery and equipment ranges from low to medium (Kalpakjian and Schmid, 2006). Due to low cost, milling was selected as preferable machining type. Besides, the number of labour in charge for this machine is less. CNC machine is widely used to perform milling process because of its small computers with large memories, low cost programmable controller and microprocessor, and also due to program editing capabilities. Yazdi and Khorram (2010) mentioned that economy of machining operation plays a key role in competitiveness in the market. With multi-tooth cutting tools, it is able to produce complex shapes. On the other hand, Itoigawa et al. (2006) realised the end milling by using MQL is much more effective than turning. According to Thangarasu and Sivasubramaniam (2012), optimum parameters are important in end milling to reduce the machining cost and time to increase the accuracy and precision.

2.3 PROCESS PARAMETERS

2.3.1 Spindle Speed

There are four important input parameters that decide the outcome of the machining of aluminium alloy. Spindle speeds are one of the important parameters.

A general recommended speed was given by Kalpakjian and Schmid (2006) for aluminium alloy of 300 m/min to 3000 m/min. Wang and Hsu (2004) set up spindle speed with a range of 1005 m/min to 3519 m/min in order to achieve a good surface roughness and at the same time to increase the material removal rate on aluminium alloy 6061-T6. By increasing spindle speed, it will increase the surface roughness due to chatter problem. The final optimum cutting speed parameter of 1257 m/min has been chosen to get the best surface finish and material removal rate. According to Yazdi and Khorram (2010) for a good surface finishing of aluminium alloy 6061-T6, the spindle speed of 754 m/min to 1508 m/min were used. The optimum value was 1508 m/min for a good surface finish. Rao and Shin (2001) were analysed on high speed face milling of 7075-T6 aluminium using carbide cutters with cutting speed range of 518 m/min to 1585 m/min. Surface roughness improved with cutting speed of 1524 m/min. On the other hand, Fuh and Wu (1995) proposed statistical model for surface quality prediction in end milling of aluminium alloy. The workpiece used was 2014 aluminium alloy, with spindle speed between 31.42 m/min to 235.6 m/min. According to their result, optimum value of cutting speed was 125.66 m/min. Another experiment carried out by Kadirgama et al. (2008) using aluminium alloy 6061-T6 as the workpiece with cutting speed between 100 m/min to 180 m/min. This experiment was carried out to find the best surface roughness in end milling of AA6061-T6 using surface response method and radian basis method. Optimum value of surface roughness was achieved at 100 m/min. Thangarasu and Sivasubramaniam (2012), a cutting speed of 3000 m/min to 12000 m/min were selected for a high speed CNC milling on aluminium alloys. The optimum spindle speed was 3544 m/min. By using aluminium silicon alloy, Boswell and Islam (2012) used end milling with spindle speed range of 135 m/min to 165 m/min. A number of different types of experiments were carried out with MQL, dry, MQL with air, air, and flooded. At 150 m/min, a minimum surface roughness result was shown with minimum quantity of lubrication. Meanwhile, Fuh and Chang (1997) used different types of aluminum alloy with different hardness. Machining of aluminum alloy 6061-T6 is related to present study machined with a cutting speed range of 40 to 160 m/min. At 90 m/min, it shows an error of 7% which is low.

2.3.2 Feed Rate

Kalpakjian and Schmid (2006) recommended a value of feed rate between 0.08 mm/tooth to 0.46 mm/tooth. Ginta et al. (2008) showed that tool life gets longer at lower feed rate. According to Wang and Hsu (2004), the feed rate was chosen as their experiment range values with 40 m/min to 90 m/min. The optimum feed rate was 90 m/min to achieve the best surface roughness and material removal rate. Reduced feed rate causes the material removal rate to reduce. On the other hand, Yazdi and Khorram (2010) used a range between 0.5 to 2 m/min feed rate values. A good surface finish obtained at 0.5 m/min. With different types of aluminum alloy (Fuh and Chang, 1997) used a feed rate of 0.03 mm/edge to 0.12 mm/edge for the peripheral milling. By using end milling, Arokiadass et al. (2012) set up feed rate between 0.04 to 0.24 m/min. Maximum feed rate for a minimum tool flank wear was chosen of 0.044 m/min. On the other hand, Rao and Shin (2001) used a value of 0.2 mm/tooth for feed rate with carbide inserts. Other experiments carried out by Fuh and Wu (1995), used a feed rate between 0.05 to 0.2 mm/edge and the optimum result was 0.03 mm/edge. Kadirgama et al. (2008) used feed rate between 0.1 mm/rev to 0.2 mm/rev. For a fine surface the result was 0.2 mm/rev. Thangarasu and Sivasubramaniam (2012), the range of feed rate on CNC milling of aluminium was 36 m/min to 108 m/min. Feed rate of 85.8 m/min would yield a better material removal rate. A constant feed rate was used by Boswell and Islam (2012) was 0.4 m/min to make a better decision with different cooling parameters.

2.3.3 Axial Depth of Cut

An axial depth of cut has an important effect on cutting force (Lai, 2000). The length of engaged flute increases with the axial depth of cut and thus increasing the cutting force which affects the cutting tools. Wang and Hsu (2004) chosen to use the axial depth of cut with range of 0.055 mm to 0.085 mm. The optimum depth of cut was 0.08 mm with better removal rate. Yazdi and Khorram (2010) used depth of cut ranging from 0.25 mm to 1.0 mm. The optimum value was 1 mm for a good surface cut. Meanwhile, Arokiadass et al. (2012) chosen a range of depth of cut within 0.5 mm to 2.5 mm and the optimum result was 0.5893 mm. In Rao and Shin (2001), the depth of cut chosen was between 0.76 mm to 2.29 mm. With depth of cut of 2.54 mm, chip thickness obtained was 0.122 mm. Fuh and Wu (1995) used depth of cut between 1 to 6 mm and the optimum depth of cut was 2.5 mm. Kadirgama et al. (2008) mentioned the best result was 0.1 mm for a fine surface cut. The range used was between 0.1 to 0.2 mm. The higher the depth of cut, the better removal rate it could yield. Fuh and Chang (1997) applied an axial depth of cut with range of 8 mm to 32 mm for peripheral milling different types of aluminum alloys. According to Thangarasu and Sivasubramaniam (2012), the depth of cut used was within 0.4 to 1 mm and the optimum result was 0.65 mm. On the other hand, with different types of cooling parameter, Boswell and Islam (2012) used a constant axial depth of cut which was 3 mm.

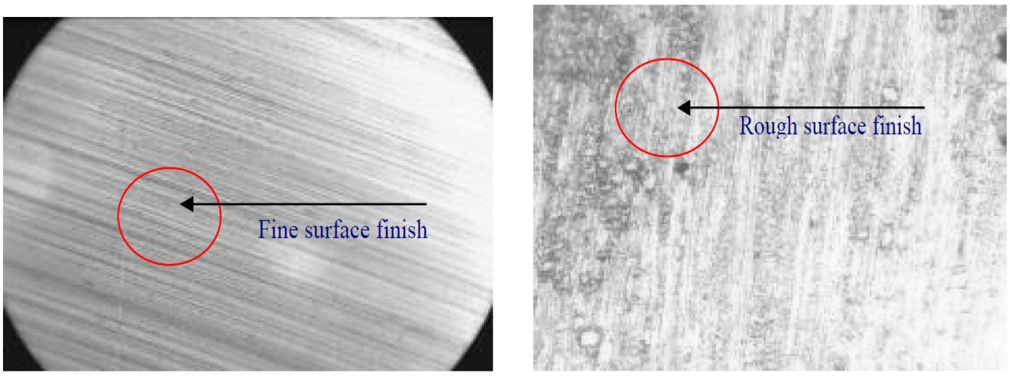
2.4 RESPONSE PARAMETERS

2.4.1 Surface Roughness

Wang and Hsu (2004) experimentally investigated that the best surface roughness was 0.04878 µm. Optimum result was chosen to get this values. In the other experiment carried by Yazdi and Khorram (2010), the best surface roughness obtained was 0.11 µm. From Fuh and Wu (1995), it showed that the minimum surface roughness was 2.95 µm. They received a better surface roughness at spindle speed up till 1524 m/min and degrades after that value. An increase in depth of cut has slightly increased the roughness of aluminum 7075-T6 surface. The surface roughness was measured every 0.8 mm. Kadirgama et al. (2008) shows a blow mould of surface roughness with 0.45 µm was produced. Figure 2.3 shows the fine surface and rough surface of AA6061-T6 after machining.

According to Kadirgama et al. (2008), the major effect of surface roughness was feed rate, followed by axial depth, cutting speed and radial depth. A good surface finish can be obtained at low cutting speed, low axial depth, high feed rate and high radial depth. Thangarasu and Sivasubramaniam (2012) concluded that an optimum value of surface roughness was in range of 20 to 40 micrometer. There were a number of parameters that related to the surface roughness of a workpiece.

Figure 2.4 shows the fish bone diagram shows the parameters involved. With 150 m/min, Boswell and Islam (2012) acquired the surface roughness about 0.7 micrometer. This was the minimum result with the usage of minimum quantity lubrication. The surface roughness was measured parallel to the feed direction (Sreejith, 2008). At all experiment, it was realized that surface of workpiece could be improved by applying lubricant.



(a) Fine surface

(b) Rough surface

Figure 2.3: Surface finish (Kadirgama et al., 2008).

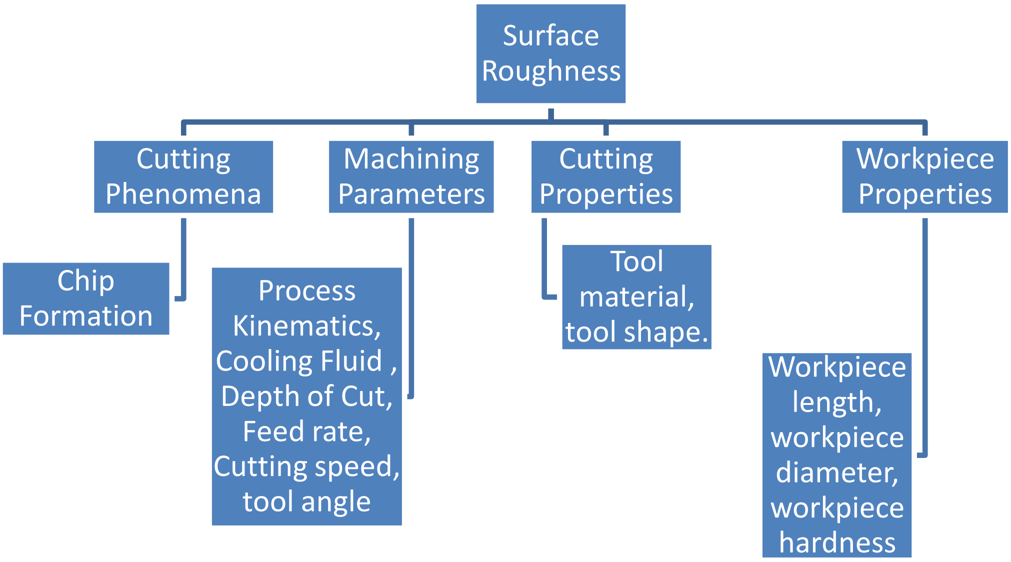


Figure 2.4: Surface roughness parameters relation to other parameters.

Source: Thangarasu and Sivasubramaniam (2012).

2.4.2 Material Removal Rate

Material removal rate is the amount of material removed in forms of chip during the milling process. Basically, the higher the material removal rate, the better it is due to faster processing and to save the power of cutting several times. Even though higher material removal rate is good. The maximum removal rate could cause the tool to wear easily and also causes higher surface roughness. Therefore, an optimum result must be chosen which has a lower surface roughness and higher material removal rate. Wang and Hsu (2004) obtained material removal rate with a value of 495 mm^3/min. Besides, Yazdi and Khorram (2010) acquired a better material removal rate with a value of 29800 mm^3/min. On the other hand, Thangarasu and Sivasubramaniam (2012) chosen material removal rate ranging from 1500 to 2000 mm^{-3} as the optimum result. Equation (2.1) is to calculate material removal rate.

$$Q = \frac{w \cdot d \cdot v}{1000} \tag{2.1}$$

where,

Q = material removal rate.

w = width of cut (mm)

d = depth of cut (mm)

v = feed rate (mm/min)

2.4.3 Tool Wear

Kalpakjian and Schmid (2006) studied the relationship of tool wear, the surface finish and integrity, dimensional accuracy, temperature rise, force and power. Tool life needs to be longer for an economical machinability. Tool life basically relates to the tool wear and the failure. Tool wear generally classified as flank wear, cutter wear, nose wear, notching, plastic deformation of the tool tip, chipping and gross fracture. Flank wear occurs at relief of the tool due to contact of the tool along machined surface and high temperatures between tool and workpieces. Nouari et al.

(2003) mentioned that coating in tools helps to reduce the tool wear and thus, increase tool life. The heat produced during the machining is critical in tool wear and workpiece surface quality especially in dry machining. Arokiadass et al. (2012), investigated that the carbide tool flank wear and the minimum flank wear obtained was 0.1102 mm. The flank wear was measured with Metzer tool maker's microscope. The workpiece used in this experiment was LM25 aluminium alloy. Boswell and Islam (2012) applied a criteria whereby a maximum notch wear of 1.0 mm. Tools were expected to reach its limit with the observation on part surface quality and burr formation. Arokiadass et al. (2012), investigated at high temperature, the flank wear increases. They have used flat end uncoated solid carbide tool. Figure 2.5 shows the flank wear in cutting tool (Arokiadass et al. 2012).

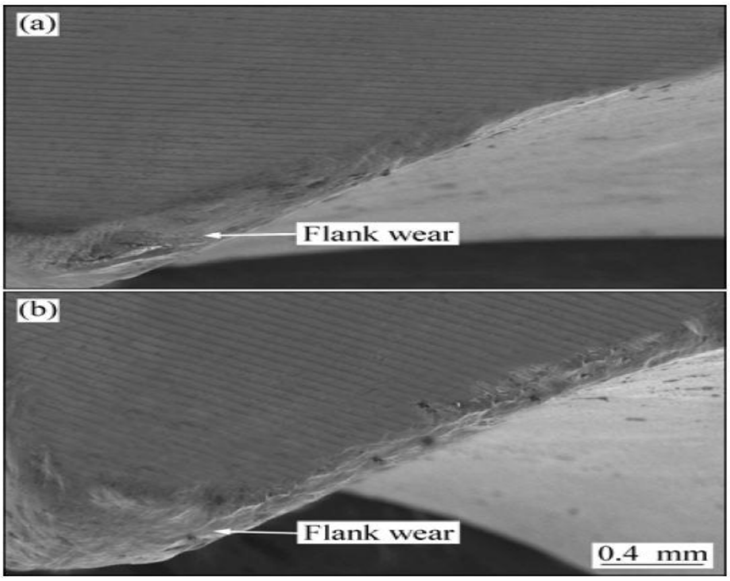


Figure 2.5: Flank wear.

Source: Arokiadass et al. (2012)

Sreejith (2008) carried out the studied that the effect of different types of coolant environment for tool wear. The adhesion of tool wear increases with increase in spindle speed. The worst rates of tool wear were recorded for dry machining. Material adhesion was checked on the tool surface such as flank, rake and clearance surface. Tool wear can be reduced by using smaller nose radius and by geometrically modifying it. Boswell and Islam (2012) created certain criteria for tool failure which were part surface, burr formation, flank wear greater than 0.3 mm or maximum notch wear of 1.0 mm, and dramatic change in tool forces and cutting power. They examined the tool wear after machining each test sample by using tool maker microscope. Smith (2008) explained that tool wear depends on a number of factor such as physical, mechanical and chemical properties, cutting insert geometry as well as cutting fluid and other machining parameters. Flank wear were described to occur at cutting tool edge`s flanks due to abrasive wear mechanism. Zhang et al. (2012), analysed tool wear based on machine vision in end milling process. Figure 2.6 shows a tool wear.

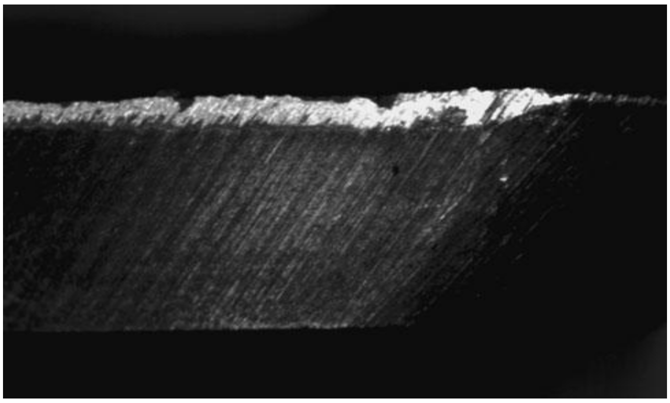


Figure 2.6: Tool wear.

There are distinctive ways of identifying tool wear, such as, in wear region the gray level is higher compared to unworn area, change of gray area is significant at cutting edge, two important vertical edges which is gray area increases along top wear edge from top to bottom and decreases from top to bottom along bottom wear area. Davim (2011) described that tool wear occurs due to continuous removal of tool wear and it can be located in two main zones that is, wear on tool rake face, which gives rise to crater like pattern and wear on the flank or tool clearance surface due to high friction tool edge with fresh machined surface. Flank wear looks like typical abrasion pattern. In a flank wear, there are three possible measurement is shown in Table 2.1. Values 0.3 mm to 0.5 mm are the maximum accepted, which was former value for finishing and latter roughing.

Table 2.1: Possible types of flank wear.

Wear types	Description
i) Uniform flank wear	Mean wear along axial depth of cut.
ii) Non-uniform flank wear	Irregular wear at several zones of cutting edge.
iii)Localized flank wear	Found on specific points.

Source: Davim (2011).

2.5 CUTTING FLUIDS

Nouari et al. (2003) explained that lubricants are useful to improve machinability, increase productivity by reducing tool wear and increasing tool life. At the same time, excess use of this lubricant has a bad side effect on the environment. But, dry machining has also become a big challenge in real life up till now. According to them, cutting fluid helps to reduce the friction of tool and workpiece contact, remove chips from tool rake face, decreases the temperature in contact zone and limits the chemical species diffusion from tool towards the chip and vice versa. Kalpakjian and Schmid (2006) stated that the lubricants are mainly used for reduce friction, reduce wear, improve material flow, act as thermal barrier especially in hot working process and act as release or parting agent which is to remove certain parts easily. Basically, there are four types of cutting fluids which is oils, emulsion, semi-synthetics and synthetics. There are certain methods of cutting fluid application such as flooding, mist, high pressure system and through the cutting tool system. However, Sreejith (2008) mentioned that most of the lubricants used in machining contain chemicals that are environmentally harmful and potentially damaging. It is difficult to be disposed and expensive to be recycled. At the same time, it could cause skin and lung cancer to person who are exposed to it. Therefore, the usage of minimal quantity of lubricant is important. The use of MQL does not have much effect on tool wear and thus has economical advantage. Itoigawa et al. (2006) studied importance of MQL in machining of aluminum alloy. They have used a different type of MQL including the MQL (rapeseed oil), MQL (synthetic ester) and MQL with water droplets also known as OoW (oil film on water droplet). MQL with water method has a large amount of cooling ability which also evaporates easily on work surface due to their size. According to his study, MQL with water has a relatively better lubrication compared to typical MQL. In Thakur et al. (2009), MQL was referred as cutting fluids of only a minute amount which is three to four times lower quantity than flood lubrication. He also mentioned that according to occupational safety and health administration (OSHA), the permissible exposure level for mist within the plant is 0.5 mg/m^3. Figure 2.7 shows the advantages of MQL compared to flooded coolant. Thakur et al. (2009) explained that tool wear could progress quickly due to high cutting temperature and strong adhesion between workpiece and tool. On the other hand, Boswell and Islam (2012) stated that the challenge of MQL is to dissipate the heat from the workpiece to ensure dimensional integrity. They used a combination of MQL and cool air in their research. For occupation, health and safety purposes, the configuration of nozzles was also considered whereby it was aligned towards the cutting zone. Smith (2008) has pointed out some important benefits of employing cutting fluids which is presented in Table 2.2.

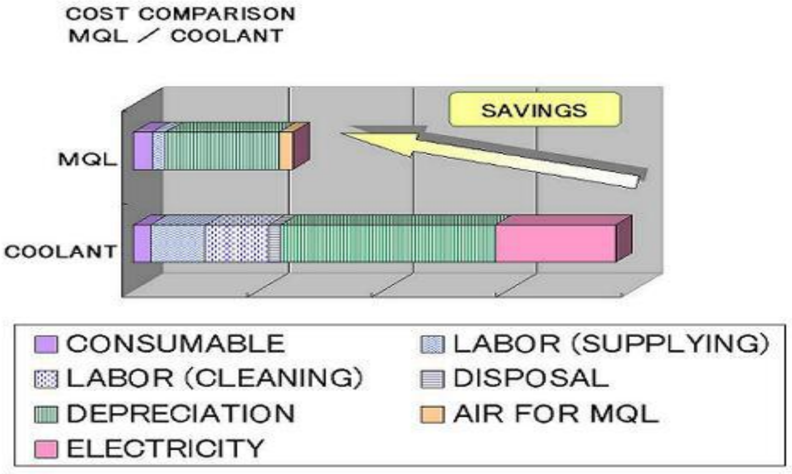


Figure 2.7: Cost comparison of MQL and flooded coolant.

Source: Thakur et al. (2009).

Table 2.2: Benefits of employing cutting fluids.

Parameters	Description
Lubrication	Reduction in insert built-up edge, reduction in spindle power consumption, lubrication of chip`s passage over insert, lowering coefficient of friction at chip and tool interface.
Cooling	Decreases heat in insert, decreases the component distortion and reduces component dimensional change.
Surface Quality	Both heat removal and frictional improvements helps in achieving better surface quality.
Tool Life	Heat removal and decrease in friction helps increasing the tool life.

Source: Smith (2006).

2.6 RESPONE SURFACE METHOD

Yazdi and Khorram (2010) experimented the difference of artificial neural network and response surface method by comparing the respective results. Both methods was used to predict models for surface roughness and material removal rate. RSM and ANN was tested by face milling of 6061-T6 aluminum. Response surface methodology shows areas in the design region whereby the process is more prone to give a desirable result. The obtained result then will be analysed. It was shown that RSM produces a better result and it is easily readable compared to ANN method. The exceptional accuracy (nearly null error) of RSM optimization was realised in rough and finishing machining case. Thangarasu and Sivasubramaniam (2012) were agreed that design of experiment based on RSM gives a better result in evaluating optimum set of parameters.

2.7 CUTTING TOOLS

There are many types of cutting tool can be used in end milling. With different cutting tools, the parameter of the experiment is changed accordingly. For every tool, the life is limited due to the interactions between the cutting tool and the workpiece. Table 2.3 shows the tool type and its general wear characteristic which was studied by Kalpakjian and Schmid (2006).

Table 2.3: General operating characteristic of cutting-tool material.

Tool Materials	**General Characteristic**	**Model of Tool Wear or Failure**	**Limitations**
High Speed Steels	High toughness, resistance to fracture, wide range of roughing and finishing cuts, good for interrupted cut.	Flank wear, crater wear	Low hot hardness, limited hardenability, and limited wear resistance.
Uncoated Carbide	High hardness over a wide range of temperatures, toughness, wear resistance, versatile and wide range of applications.	Flank wear, crater wear	Cannot use at low speeds because of cold welding of chipping and micro chipping.
Coated Carbides	Improved wear resistance over uncoated carbides, better frictional and thermal properties.	Flank wear, crater wear	Cannot use at low speeds because of cold welding of chipping and micro chipping.

Source: Kalpakjian and Schmid (2006).

2.8 CHIP FORMATION

Rao and Shin (2001) carried out an experimental studied that the chip shape and texture by collecting it during high speed face milling of aluminum 7075-T6. There are no major changes noted by changing the spindle speed and depth of cut. However, the change showed up at different feed rates. Higher feed created shorter chips due to chip segmentation. A continuous chip without any segmentation was observed at lower feed rate. Nevertheless, this opposes the previous research which created continuous chips at higher speed due to lower hardness and higher thermal properties of aluminum (Rao and Shin, 2001). Figure 2.8 shows the effect of feed on the chip formation.

(a) Feed = 0.004 ipt (b) Feed = 0.008 ipt (c) Feed = 0.015 ipt

Figure 2.8: Effect of feed on chip formed.

Source: Rao and Shin (2001).

Kalpakjian and Schmid (2006) classified chip types into four including continuous, built-up edge, serrated or segmented and discontinuous. Generally continuous chips produce good surface finish but it creates problem by tangling on tool during machining as well as the chip-disposal system. Built-up edge, on the other hand, has become one of the major effect on surface roughness of workpiece. Kalpakjian and Schmid (2006) also mentioned that built-up edge can be reduced by increasing spindle speed, decreasing depth of cut, increasing rake angle, using sharp tool, and using effective cutting fluid. Serrated chips are semi-continuous chips with large zones of high shear strain. It has a saw-tooth like appearance. Discontinuous chips might for due to very low or very high spindle speeds, large depth of cuts, low rake angles, lack of effective cutting fluid and due to vibration or chatter of tool.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This project is mainly intended to machining the aluminum alloy 6061-T6 under appropriate machining parameter to achieve a minimum tool wear, maximum material removal rate and minimum surface roughness. The effect of minimum quantity lubrication on machining performance parameters is also investigated. Aluminum alloys workpieces are difficult to be machined due to its properties which is a soft material. This causes problem when finding the optimum machining parameters. Most researches were studied about steel alloy milling however very little research was done on aluminum alloy. This chapter will cover the methods and procedures used to develop this research. It includes the preparation and design of experiment. There are some tools that were used in this research as an aid such as dynamometer. Further machining information were discussed in this chapter too.

3.2 WORKPIECE MATERIALS

The aluminum alloy is supportive and encouraged by the industries especially, aircraft industries. The usage of aluminum alloy as an aeroplane body parts needs it to be more precisely machined for a high accuracy and increased safety. However, less study were conducted on aluminum alloy 6061-T6 machining. Therefore, this research is done to expose the machinability of aluminum alloy 6061-T6 under minimum quantity lubrication. The study of aluminum alloys workpiece was done with different types of cutting tools. To achieve a good surface roughness and material removal rate, the speed of machining was set to optimum. The next sub section will discuss details related to mechanical, physical and thermal characteristic of workpiece materials.

Table 3.1: Physical properties of AA6061-T6 (Kadirgama et al., 2008).

Component	**Si**	**Mn**	**Mg**	**Ti**	**Zn**
Weight (%)	0.4-0.8	Max 0.15	0.8-1.2	Max 0.15	Max 0.25

Fuh and Chang (1997) compared the material hardness of AA6061-T6 with the other aluminum alloys. The Brinell hardness was 91 HB. It has a medium value compare to other alloys. Table 3.1 and 3.2 shows the chemical properties and mechanical properties of AA6061-T6 prepared by Kadirgama et al. (2008). Table 3.3 explains the thermal properties of aluminum alloy.

Table 3.2: Mechanical properties of AA6061-T6.

Properties	**Value**	**Unit**
Hardness, Brinell	95	-
Hardness, Knoop	120	-
Hardness, Rockwell A	40	-
Hardness, Rockwell B	60	-
Hardness, Vickers	107	-
Ultimate Tensile Strength	310	MPa
Tensile Yield Strength	276	MPa
Elongation at Break	12	%
Elongation at Break	17	%
Modulus of Elasticity	68.9	GPa
Density	2.7	g/cc

Source: Kadirgama et al. (2008).

Table 3.3: Thermal characteristic of aluminum alloy 6061-T6.

Thermal Properties	**Value**	**Unit**
Specific Heat Capacity	0.896	J/g-°C
Thermal Conductivity	167	W/m-K
Melting Point	582 - 652	°C

Meanwhile, Shankar et al. (2005) have carried out a research on AA6061-T6 deformation. This research was related to plastic deformation in AA6061-T6 during machining. AA6061-T6 is said to be highly potential for fabricating thermally stable, high strength and light weighted nanostructure material through plastic deformation. Kalpakjian and Schmid (2006) generally tabulated the type of machining that aluminum alloy would normally undergoes and showed that this alloys are well known for machining such as milling. Figure 3.1 shows the aluminum alloy workpiece in block form. By using drilling, two holes have been made into the workpieces. This is to ensure that the workpiece can be easily screwed onto the dynamometer. Dynamometer usually used to measure the cutting force, but it has been used to aid the clamping of workpieces. This reduces the time of setting (0,0) coordinate in machine every time the workpiece being removed to check the weight. The dimension of the workpiece is 100 × 100 × 30 mm.

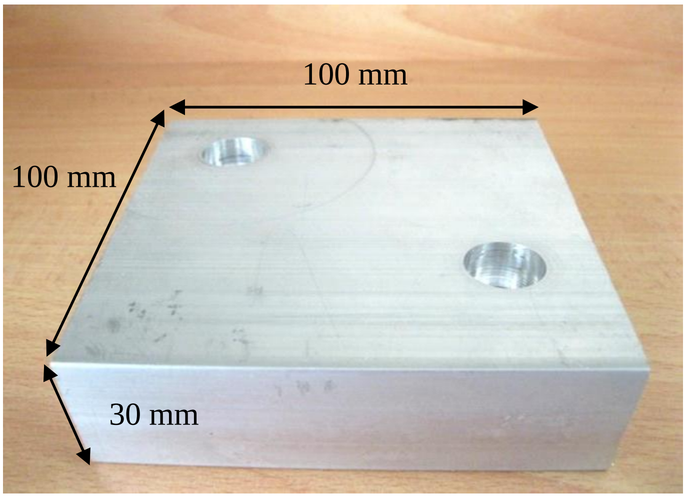


Figure 3.1: Workpiece of aluminum alloy 6061-T6.

3.3 PROCESS PARAMETERS

Based on previous literature, an end milling has three main input parameters that are always needed to be considered, in order to control the machining output parameter. The three main variables are spindle speed, feed rate, and depth of cut. Tool type has been varied to find the best tool to cut the aluminum alloy and to analyse the difference of each tool effect on workpiece. For this study, the flow of

MQL has been varied to compare the results and to analyse the minimum MQL flow rate. Lubrication is important to produce a good surface cut. There are two types of machining conditions including the flooded and MQL. Spindle speed is also known as cutting speed of the machine whereby it is the rotational frequency of spindle which usually measured in revolutions per minute. Depth of cut is the measure of depth of the workpiece cut from the surface of workpiece before cut and feed rate is the velocity of cutter moving forward against the workpiece.

3.3.1 Spindle Speed

Spindle speed has an important effect on surface roughness and material removal rate of the workpiece (Kalpakjian and Schmid, 2006). It also affects the tool wear progress. An optimum value of spindle speed is important especially in aluminum alloy machining. This is because of parameters in machining has effect on many other response parameters. Table 3.4 summaries the range of spindle speed used in the previous researchers. It can be seen that the spindle speed range is very low for every aluminum alloy cuts. The value of spindle speed for this study has been identified which was in the range of between 881 rpm to 1192 rpm. This value were also in the range of manufacturer`s recommendation.

Table 3.4: Spindle speed comparison.

Machining Type	Work Piece	Range	Unit	References
One-Pass Milling	Al 6061-T6	2000-7000	rpm	Wang and Hsu (2004)
Orthogonal Cutting	Al 6061-T6	54-193	m/min	Dhananchezian et al.(2009)
End Milling	LM25 Al alloy	2000-4000	rpm	Arokiadass et al. (2012)
Peripheral Milling	Al alloys	40-160	m/min	Fuh and Chang (1997)
Face Milling	Al 7075-T6	500-1585	m/min	Rao and Shin (2001)
End Milling	Al 7075	700	m/min	Coz et al. (2012)
End Milling	Al alloy 2014	31.42 -157.8	m/min	Fuh and Wu (1995)
Turning	Al alloy 6061	50-400	m/min	Sreejith (2008)
Orthogonal Cutting	2024–T351 Al alloy	30-360	m/min	List et al. (2005)
End Milling	Al SiC	56-224	m/min	Babu et al.(2008)
End Milling	Al 6061-T6	100-180	m/min	Kadirgama et al. (2008)
End Milling	Al-Si alloy	135-165	m/min	Boswell and Islam (2012)

3.3.2 Feed Rate

Feed rate is an important parameter due to the fact that it affects the surface roughness of the workpiece. The formation of chip was influenced by the feed rate. Feed rate value used in previous researches are shown in Table 3.5.

Table 3.5: Feed rate comparison.

Machining Type	Work Piece	Range	Unit	References
One-Pass Milling	Al 6061-T6	2.0-4.5	mm/tooth	Wang and Hsu (2004)
Orthogonal Cutting	Al 6061-T6	0.079 - 0.159	mm/rev	Dhananchezian et al. (2009)
End Milling	LM25 Al alloy	0.02-.06	mm/rev	Arokiadass et al. (2012)
Peripheral Milling	Al alloys	0.03 -0.12	mm/edge	Fuh and Chang (1997)
Face Milling	Al 7075-T6	0.2	mm/tooth	Rao and Shin (2001)
End Milling	Al 7075	0.2	mm/tooth	Coz et al. (2012)
End Milling	Al alloy 2014	0.03 -0.2	mm/edge	Fuh and Wu (1995)
Turning	Al alloy 6061	0.15	mm/rev	Sreejith (2008)
Orthogonal Cutting	2024–T351 Al alloy	0.1-0.3	mm/rev	List et al. (2005)
End Milling	Al SiC	0.3-1.5	mm/sec	Babu et al.(2008)
End Milling	Al 6061-T6	0.1-0.2	mm/rev	Kadirgama et al. (2008)
End Milling	Al-Si alloy	400	mm/min	Boswell and Islam (2012)

3.3.3 Depth of Cut

Depth of cut is significant in maximizing the material removal rate of workpiece. With higher depth of cut, more material can be removed but it also could damage the surface finish and the tool. Therefore, an optimum depth of cut is important. Table 3.6 explains the range of depth of cut used in previous studies. Based on Table 3.6, most of the CNC milling cut does not exceed 6 mm of depth.

Table 3.6: Depth of cut comparison.

Machining Type	**Work Piece**	**Range**	**Unit**	**References**
One-Pass Milling	Al 6061-T6	0-055-0.085	mm	Wang and Hsu (2004)
Vertical Milling	Al 6061-T6	0.25-1	mm	Yazdi and Khorram (2010)
End Milling	LM25 Al alloy	0.5-2.5	mm	Arokiadass et al. (2012)
Peripheral Milling	Al alloys	8-32	mm	Fuh and Chang (1997)
Face Milling	Al 7075-T6	0.76-2.29	mm	Rao and Shin (2001)
End Milling	Al 7075	4	mm	Coz et al. (2012)
End Milling	Al alloy 2014	1-6	mm	Fuh and Wu (1995)
Turning	Al alloy 6061	1	mm	Sreejith (2008)
End Milling	Al SiC	0.4-2	mm	Babu et al.(2008)
End Milling	Al 6061-T6	0.1-0.2	mm	Kadirgama et al. (2008)
CNC Milling	Aluminum	0.4-1	mm	Thangarasu and Sivasubramanian (2012)
End Milling	Al-Si alloy	3	mm	Boswell and Islam (2012)

3.3.4 Cutting Tool

This experiment has been designed to be completed with three inserts whereby two are coated and one are uncoated. The tool condition will be visually checked for progressive tool wear in every single cut.

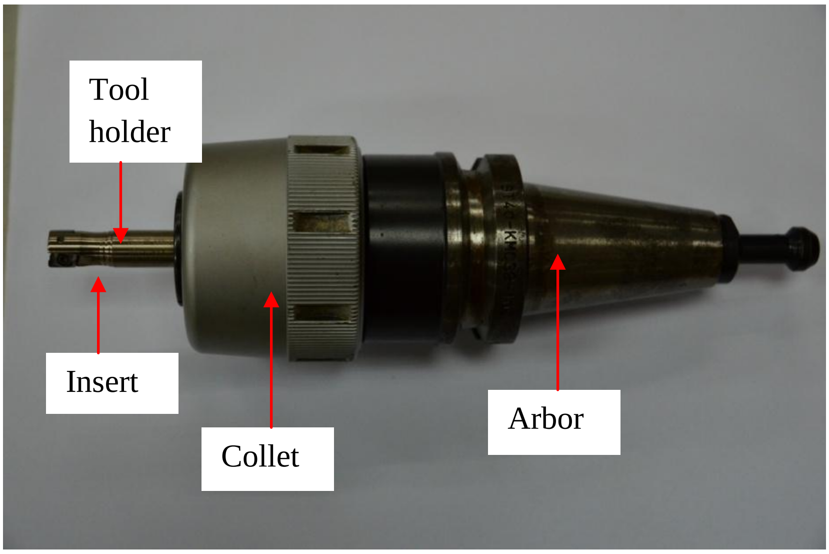


Figure 3.2: Insert tighten on tool holder.

For every cut, the tool must be tightened as firm as possible to avoid unnecessary vibration during cutting which may lead to many other problems. Figure 3.2 shows the insert tightened on tool holder. The same procedure was used for the coated and uncoated tool. Figure 3.3 shows the uncoated insert, (TiN) coated and (TiAl)N coated insert. This carbide inserts will then be mounted on the 12 mm diameter tool holder. Inserts rotates at higher spindle speed and feed rate due to the insert contact surface which are small. This large parameters will make sure the surface contact between insert and workpiece are more.

(a) (b) (c)

Figure 3.3: (a) Coated 1235, (b) coated 2235, and (c) uncoated 4615 carbide

3.4 RESPONSE PARAMETERS

Surface roughness, material removal rate, tool wear, and chip formation are the response parameters in this study. These parameters are defined the performance of the machinability of aluminium alloy 6061-T6 using end milling.

Surface Roughness: The surface roughness in this study is measured by using Perthometer. Perthometer is a portable surface roughness tester used to generate the data of surface smoothness. The contact of tool and workpiece is caused surface roughness. The interaction of two rough surface happens in small area and it is known as real area of contact. This surface roughness speeds up the tool wear progress. From Figure 3.4, the area within the roughness profile and the middle line is known as average surface roughness, R_a.

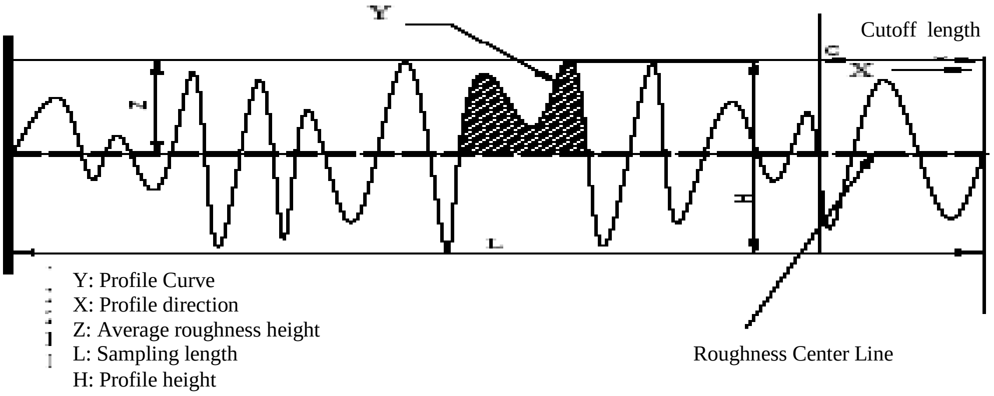


Figure 3.4: Surface roughness profile.

Source: Thangarasu and Sivasubramaniam (2012).

Surface roughness, R_a can also be written as Equation (3.1):

$$R_a = \frac{1}{L}\int_0^L |Y(x)|dx \tag{3.1}$$

Meanwhile, Equation (3.2) explains the trapezoidal rule,

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|Yi| \tag{3.2}$$

Equation (3.2) shows the arithmetic average deviation from mean line, *L* is known as the sampling length and *Y* is the alignment of the profile curve. Equation (3.3) can be used to predict average roughness for surface produced by single point tool.

$$R_i = \frac{f^2}{32NR} \tag{3.3}$$

whereby, R_i is the theoretical arithmetic surface roughness (mm), *f* is feed (mm), and *NR* is known as nose radius at tool point. As the nose radius increases, the degree of roundness of tool tip increases. In this study, the tool tips used are sharp as the material are less heat resistive and thus does not accelerate the tool wear.

Tool Wear: Tool wear happens due to the friction between the rotating tool and moving workpieces in machining. This is minimized the tool life and thus, increases the surface roughness of workpiece (Zhang et al., 2001). Minimum level of tool wear is important in machining process. Therefore, the tool needs to be inspected for every cut. This will be a lengthy process. Mostly tool wear can only be identified under a high focus microscope such as scanning electron microscope.

Material Removal Rate: For every cut, the process parameters will be different. Therefore, this is affected the material removal rate. This is because the spindle speed and the feed rate changes. With a maximum material removal rate, a product can be machined faster and thus it is economical and expected. The material removal rate of a machined product can be calculated by Equation (3.4).

$$Q = \frac{a_p \cdot a_e \cdot v_f}{1000} \tag{3.4}$$

where,

$Q =$ Material removal rate ($cm^3 / \min$)

a_p = Depth of cut (mm)

a_e = Cutting width (mm)

v_f = Feed rate (mm/min)

3.5 DESIGN OF EXPERIMENTS

It is always important to choose the best and optimum cutting parameters but it is not an easy task as there are many parameters are related to each other and needs to be considered. This experiment was designed by using central composite design (CCD). This is suitable and advanced due to one of its feature which is blocking. The blocking method allows the user to study the total set of data collection together.

Table 3.7: Design of experiment matrix for MQL uncoated and coated carbide inserts.

Levels	Speed (rpm)	Feed rate (mm/min)	Depth of Cut (mm)	Flow rate (ml/min/nozzle
-2	5252	288	0.52	0.0130
-1	5300	318	1.0	0.0160
0	5400	379	2.0	0.0220
1	5500	440	3.0	0.0275
2	5548	469	3.5	0.0300

Table 3.8: Design of experiment matrix for flooded uncoated and coated carbide inserts.

Levels	Speed (rpm)	Feed rate (mm/min)	Depth of Cut (mm)
-2	5237	279	0.367
-1	5300	318	1.0
0	5400	379	2.0
1	5500	440	3.0
2	5563	479	3.633

Table 3.9: Experimental data for MQL coated and uncoated carbide inserts.

No.	**D.O.C (mm)**	**Speed (rpm)**	**Feed Rate (mm/min)**	**MQL flow rate (ml/min)**
1	3	5500	318	0.48
2	1	5300	440	0.825
3	1	5300	318	0.48
4	2	5400	379	0.9
5	2	5400	469.43	0.6525
6	3	5300	440	0.48
7	3	5500	318	0.825
8	1	5300	318	0.825
9	2	5548.25	379	0.6525
10	2	5400	288.56	0.6525
11	2	5400	379	0.39
12	3	5500	440	0.825
13	2	5251.74	379	0.6525
14	2	5400	379	0.6525
15	1	5500	440	0.825
16	3	5300	318	0.825
17	3.48	5400	379	0.6525
18	3	5300	318	0.48
19	1	5500	318	0.825
20	0.51	5400	379	0.6525
21	1	5500	440	0.48
22	1	5300	440	0.48
23	1	5500	318	0.48
24	3	5500	440	0.48
25	2	5400	379	0.6525
26	3	5300	440	0.825

Table 3.9 and 3.10 shows the experimental data used for uncoated and coated carbide cutting insert. Meanwhile, Table 3.7 and 3.8 shows the design of experiment matrix used in this experiment.

Table 3.10: Experimental data for flooded coated and uncoated inserts.

No.	D.O.C (mm)	Speed (RPM)	Feed Rate (mm/min)
1	2	5400	379
2	1	5300	318
3	2	5400	379
4	3	5500	318
5	3	5300	440
6	1	5500	440
7	1	5500	318
8	2	5400	379
9	2	5400	379
10	1	5300	440
11	3	5300	318
12	3	5500	440
13	2	5400	279.38
14	2	5563.29	379
15	2	5400	379
16	3.63	5400	379
17	2	5236.70	379
18	0.36	5400	379
19	2	5400	379
20	2	5400	478.61

3.6 WORKPIECE PREPARATION

Before machining, the workpiece is fixed onto the vice by clamping it tightly. The workpiece is then cleaned on the surface with soft cloth to prevent damage during cutting. The workpiece is clamped tightly at least 12 mm on top of a parallel bar so that it is positioned horizontally and the workpiece is not slanted. Figure 3.5 shows one of the machine to complete the cuts with coated and uncoated carbide inserts.. The initial position of workpiece is marked with a marker on the vice so that the next workpieces do not need to be set their origin. This reduces the time of setting the origin point coordinate on the machine. Figure 3.5 shows the clamped aluminium alloy workpiece.

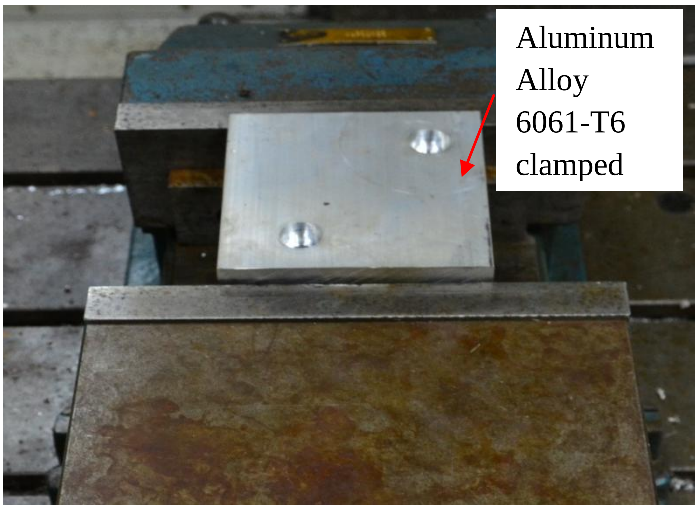


Figure 3.5: Workpiece clamped on machine.

3.7 EXPERIMENTAL SETUP

This experiment was performed with the help of CNC milling machine, HAAS VF-6, as shown in Figure 3.6. By using minimum quantity lubricant, the nozzles were attached to the machine. By using coated carbide and uncoated carbide, the experiments were repeated.

Figure 3.6: CNC end milling machine HAAS VF-6

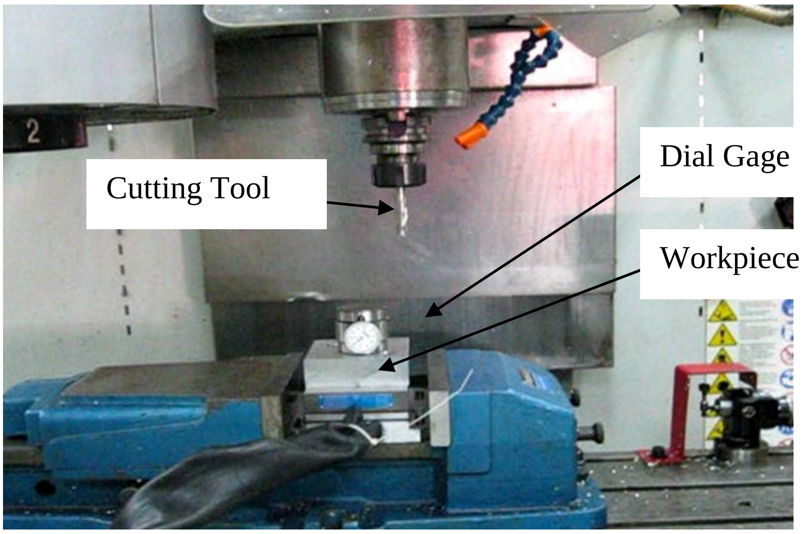


Figure 3.7: Z-depth compensation being set by dial gage.

Table 3.11: Specification of CNC end milling machine HAAS VF-6.

TRAVELS	**Metric**
X Axis	1626 mm
Y Axis	813 mm
Z Axis	762 mm
TABLE	**Metric**
Length	1626 mm
Width	711 mm
T-Slot Width	16 mm
T-Slot Center Distance	125.0 mm
Number of Std T-Slots	5
Max Weight on Table (evenly distributed)	1814 kg
SPINDLE	**Metric**
Max Rating	22.4 kW
Max Speed	8100 rpm
Max Torque	122 Nm @ 2000 rpm
Drive System	Inline Direct-Drive
Max Torque w/opt Gearbox	339 Nm @ 450 rpm
Bearing Lubrication	Air/Oil Injection
Cooling	Liquid Cooled
GENERAL	**Metric**
Air Required	113 L/min, 6.9 bar
Coolant Capacity	360 L
Machine Weight	9526 kg

Table 3.11 shows the specification of the machine HAAS VF-6. The block are then tighten on top of a parallel bar. This is to make sure the aluminum block is rigid and does not incline or decline every time it is machined. It is then will removed to measure the weight. After it is mounted on the vice and parallel bar, the z-depth and (0,0) coordinate will be defined by coding in the machine. Figure 3.7 shows the z coordinate origin being set by using a dial gage. Figure 3.8 shows (0,0) coordinate of *x* and *y* being set with *H* spindle. By using hand jog, the table is moved to a position so that *H* spindle which rotates at 500 rpm offset from its straight position. Then, in the coding, G54 positions is defined by adding -5.0 mm to *x* and *y* position due to the spindle radius. Once the *H*-spindle is set, it is removed and tool is fixed into the arbour. Table 3.12 presents the coding used for machining purpose. The coding changes for every cut according to the parameter that was set. For every cut, the work piece is removed to check the weight change.

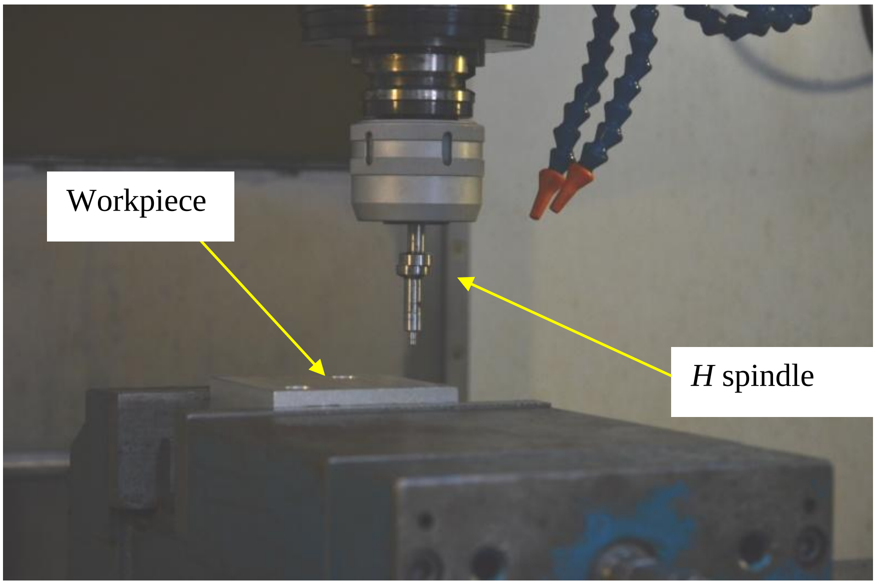


Figure 3.8: G54 setting with H spindle.

Table 3.12: Machine coding used for cutting workpiece.

Line No.	Coding
1	T1 M06;
2	G90 G54 G00 X10. Y-10. ;
3	S5400 M03;
4	G43 H01 Z5. ;
5	G01 Z-2. F379. ;
6	X-115. F379. ;
7	G00 Y-46. ;
8	M01 ;

After setting up the coding, the MQL flow was set up. The flow of MQL was turned on once the machine spindle starts to rotate. Once the first cut finished, the cutting tool was removed followed by the work piece and chips was collected. Then, the tool was brought to another lab for flank wear check by using optical video measuring system. Meanwhile, work piece was brought to material lab to check the weight difference for the purpose of material removal rate measurement during analysis. For every work piece, there was four cuts with different parameter according to Table 3.8 and Table 3.10.

Table 3.13: Coding explanation.

Codes	Description
G90	Absolute programming positioning.
G54	Part zero offset location.
G00	Used when not cutting, to move to next position or to move away after machining.
G43	Tool length compensation.
G01	Used during machining and metal removing process.
M06	Tool changing command.
M03	Commence to rotate spindle clockwise.
M01	Optional program stop command.

3.8 SURFACE ROUGHNESS MEASUREMENT

The measurement of surface roughness was checked by using portable roughness tester or Perthometer. Perthometer will be able to find a very small difference in surface roughness. Its stylus is very sensitive. Figure 3.9 shows the

MahrPerthometer. Before using this tool, the work piece surface must be cleaned from any type of impurities on the surface to avoid the miscalculation on surface roughness. Once the material is placed on a horizontal surface, the Perthometer is turned on and reading is recorded in the computer as a data.

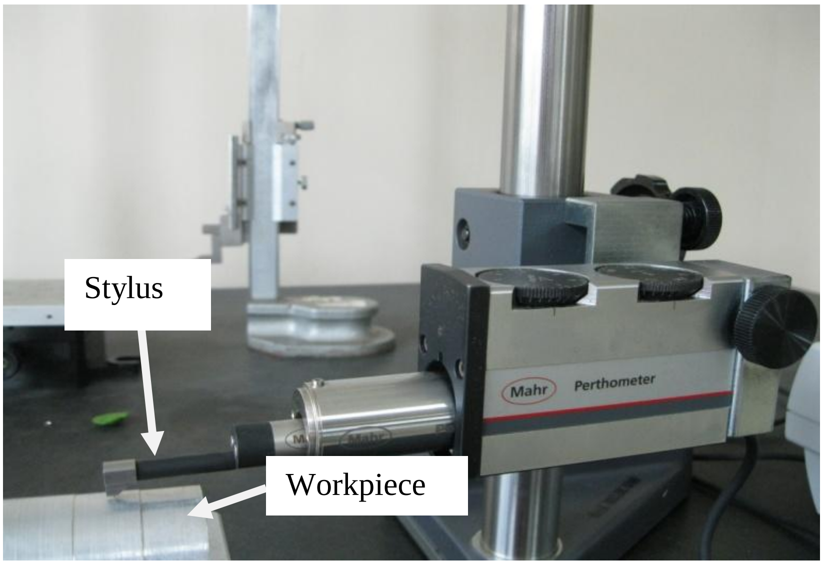
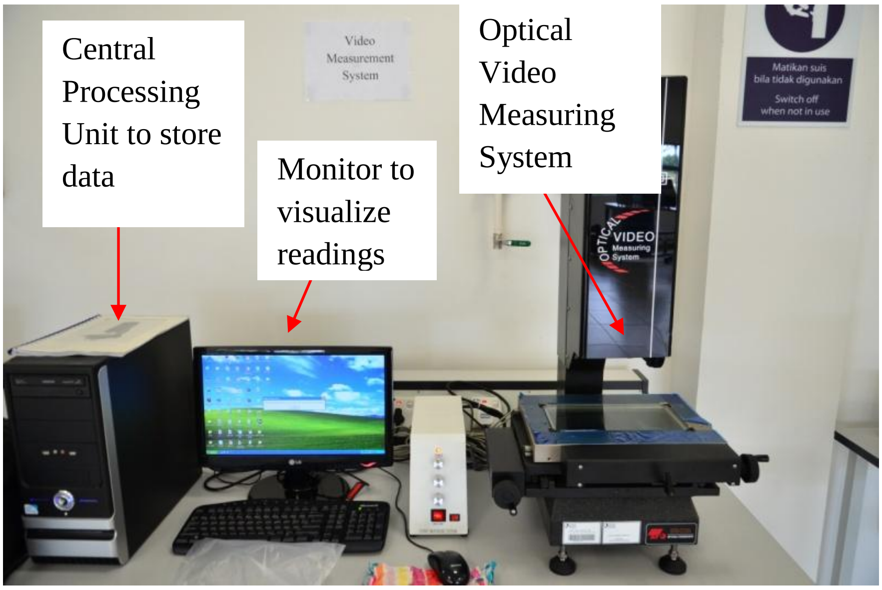


Figure 3.9: Surface roughness measuring device.

3.9 TOOL WEAR MEASUREMENT

This experiment is to study the effect of machining parameter towards the tool wear. Since the significant part for machining is the tool flank. The flank wear is examined in every cut and the dimensions are recorded. With the help of optical video measuring system, the tool wear has been analysed and it has been saved for future comparison of tool flank changes. Figure 3.10 shows the optical video measuring system model SOV-2010 (N/A) used for the tool flank wear measurement and Figure 3.11 shows the tool flank wear measuring method by using scanning electron microscope. To make sure the tool is not damaged badly, every dimension of tool flank is recorded for safety and future analysis. The uniform flank wear dimension is 0.3 mm according to ISO 8688 (Boswell and Islam, 2012). Once this dimension is achieved by the tool, a new tool will be used for further cutting. Other than optical video measuring system, a much more precise microscope was also used which is also known as scanning electron microscope (SEM). Scanning electron microscope enables us to take reading further and better whereby the cracks on tool will be visible unlike using optical video measuring system. Figure 3.11 shows the image that was taken under scanning electron microscope.


Central Processing Unit to store data

Monitor to visualize readings

Optical Video Measuring System

Figure 3.10: Optical video measuring system.

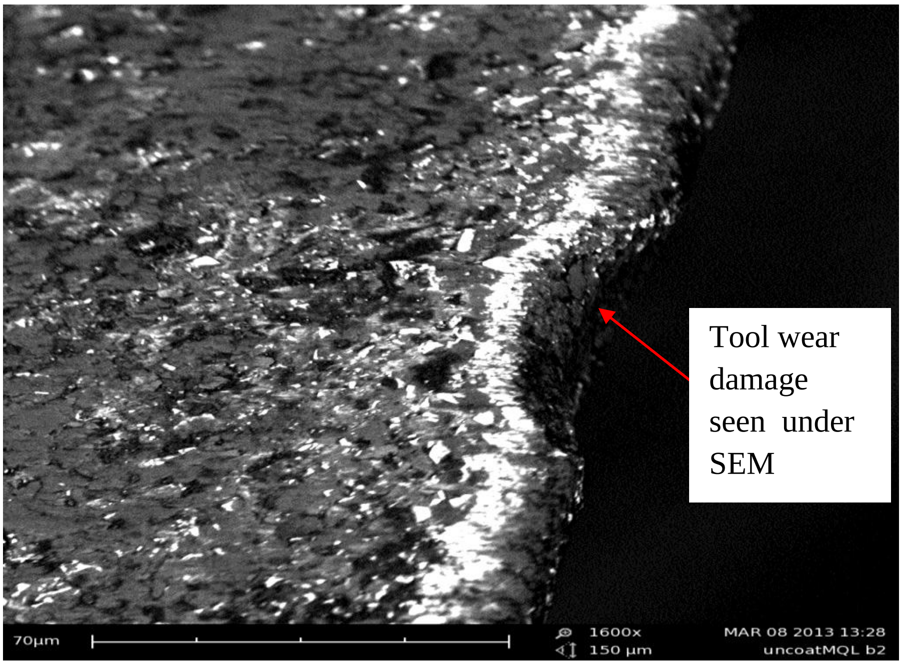

Tool wear damage seen under SEM

Figure 3.11: Tool wear taken under scanning electron microscope.

3.10 CUTTING FLUID

Lubricants aid the cutting tool to remove metal without being damaged. In other words, it acts as an agent that removes the heat due to interaction between the cutting tool and the work piece. Flooded coolant could cause many types of harms to the environment and human being (Nouari et al., 2003) . MQL also helps to reduce the wasted coolant and ease the chip collection. In this experiment, MQL was delivered to the machining by using UNIST Coolube as shown in Figure 3.12. This system delivers a very good lubrication amount in minimum quantity. It is biodegradable and environmental friendly. This system comes with six nozzles and air pump for each nozzle. By opening desired amount of lubricant flow, the air pressure can be altered so that the lubricant will disperse around the cutting tool. For this study, three nozzles were used and the nozzles were configured at 120 degrees of angle away from each other. This is to ensure the dispersion of MQL flow covers the cutting tool. Besides, it was also configured so that the edge of MQL nozzle faces the cutting tool tip. The tip of MQL nozzle was set up 0.6 mm higher than the edge of cutting tool. Therefore, it is not touch the work piece during cutting. Figure 3.13 shows the configuration of MQL nozzle around the cutting tool.

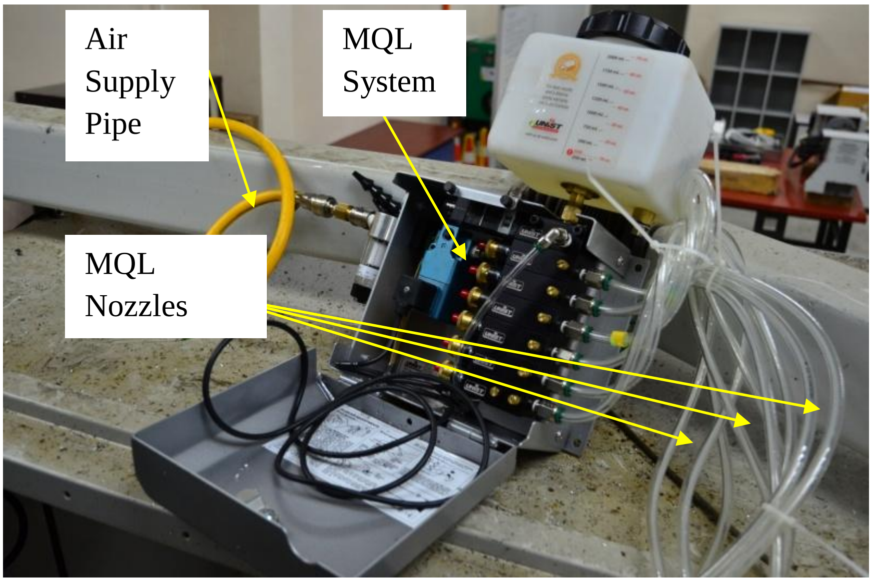


Figure 3.12: UNIST Coolube MQL supply.

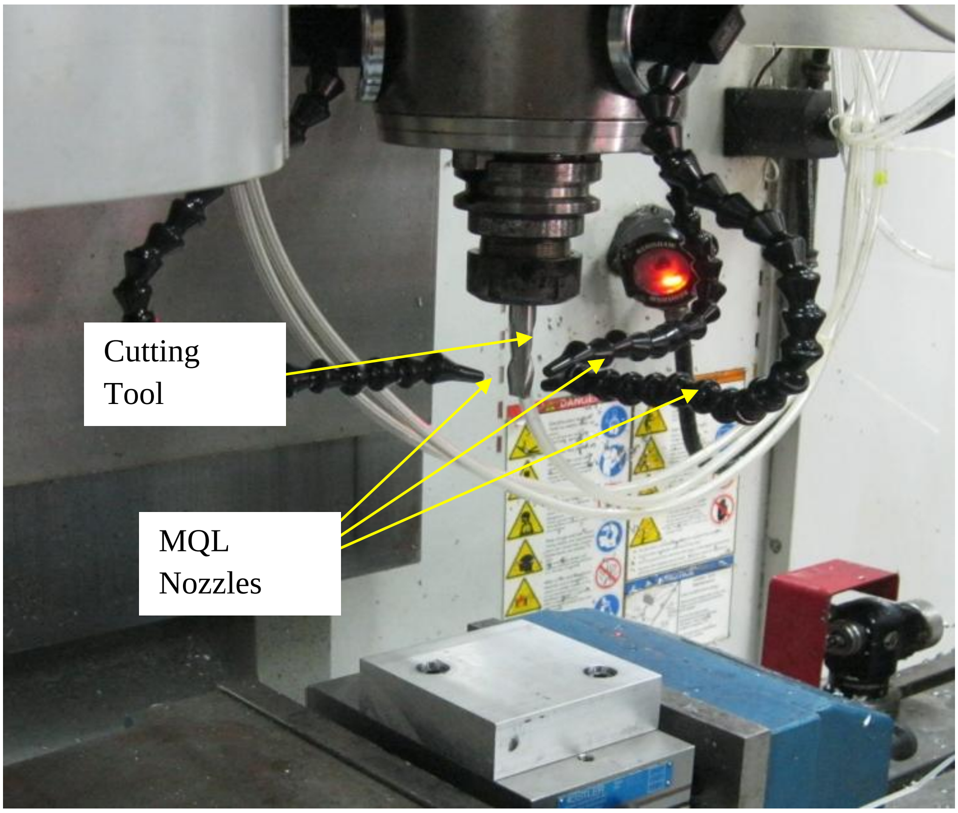
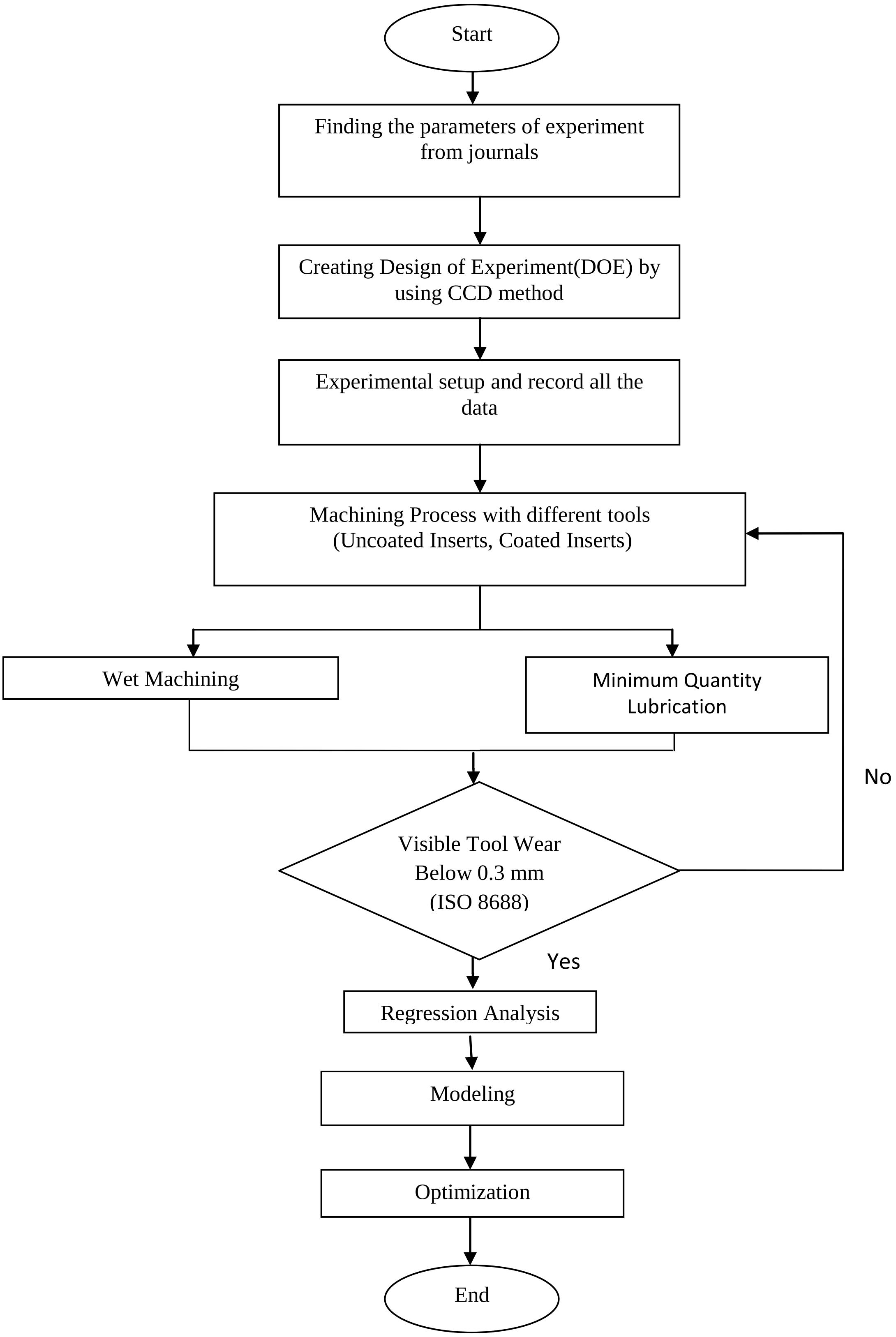


Figure 3.13: Nozzle configuration around the cutting tool.

3.11 FLOW CHART OF STUDY

The flowchart of the present study is as follows:



3.12 SUMMARY

This chapter described the methods to accomplish the experiment. All the parameters selected were based on the previous published literatures and recommendation from tool manufacturers. The next chapter will analyze all the collected data. This data then will be presented for comparison and explanations.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the experimental study of the tool wear by comparing flooded and MQL from the experimental data and to find the best carbide insert for machining. Regression analysis was performed to develop a mathematical model. Progressions of abrasive wear were mainly considered in this chapter. Since the progression of tool wear is slow and less, therefore the wear cannot be identified by direct visualization. By using scanning electron microscope, tool wear has been checked for every 50 cuts. Mathematical model of tool wear are then generated to make multi objective optimization. This will help further to identify the optimized parameters that can be used for end milling machining of Al alloy 6061-T6.

4.2 EXPERIMENTAL STUDY

4.2.1 Regression Analysis

In this study, finding tool wear was a difficult process as the work piece material are soft and the resulting tool wear are too small for consideration. Therefore, 10 experimental parameters were selected for each insert based on the total design of experiments and 50 cuts were done for each experiment. Regression analysis was chosen as the analysis method and statistical software were used to generate the values. R-square values were used to test the significance of the mathematical modelling. Table 4.1 shows the corresponding value of tool wear for chosen 10 experiments and Table 4.2 shows the corresponding R-square values generated for each insert. Besides, to make sure the overall values fits in properly, R-square values was identified. Table 4.2 shows the corresponding R-square values for each inserts. Based on Table 4.2, the R-squared values show that the mathematical model is significant and adequate in order to determine the tool wear. The coefficients generated can be used for mathematical modelling.

Table 4.1: Experimental values chosen to analysis tool wear data.

Expt No.	**D.O.C (mm)**	**Speed (RPM)**	**Feed rate (mm/min)**	**MQL Flow rate (ml/min)**	**Tool Wear (µm)**		
					Coated 1235	**Coated 2235**	**Uncoated 4615**
1	1	5300	440	0.825	41	61.28	29.31
2	2	5400	379	0.9	79.9	69.95	36
3	2	5400	469	0.6525	44.84	62.96	20.71
4	2	5548	379	0.6525	82.64	47.83	43.2
5	2	5400	379	0.6525	69.95	64.48	31.4
6	3	5300	318	0.825	67.21	71.6	43.1
7	3.5	5400	379	0.6525	80.11	93.04	35.95
8	1	5500	318	0.825	76.98	97.44	30.33
9	3	5500	440	0.48	77.76	69.19	26.44
10	3	5300	440	0.825	77.37	63.86	26.9

Table 4.2: R-squared values for tool wear.

	R-square value
Coated Carbide 1235	0.8550909
Coated Carbide 2235	0.977406
Uncoated Carbide 4615	0.904898

4.2.2 Development of Mathematical Model

Based on the regression analysis, the coefficients for each variable was determined. Basically RSM was the main method that was used to develop the mathematical models. First order and second order of RSM model was developed based on the tool wear results. Using this method, the unknown coefficients can be found for its corresponding variables. A linear model shown in Equation 4.1 consists of responses correlation and independent variables.

$$
\begin{aligned}
&\mathrm{y} = \mathrm{a} \times \text{Feed Rate} + \mathrm{b} \times \text{Depth of Cut} + \mathrm{c} \times \text{Spindle Speed} \\
&+ \mathrm{d} \times \text{MQL Flow rate} + \mathrm{e}
\end{aligned} \tag{4.1}
$$

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

The Equation (4.1) can then be related with quadratic equation which also can be written as in Equation (4.2)

$$
y'' = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{44} x_4^2 \tag{4.2}
$$

whereby, x_0 is a dummy variable with value of 1, x_1 = depth of cut, x_2 = speed, x_3 = feed rate and x_4 = MQL Flow rate. The constants for quadratic terms was generated from statistical software, Matlab. Equation (4.3), (4.4) and (4.5) represents the second order model for coated and uncoated carbide.

For coated carbide insert (CTP 1235):

$$
\begin{aligned}
&y'' = 2220.0699889\, x_0 + 11.228769911\, x_1 + -1.0310808401\, x_2 + 1.38181139\, x_3 \\
&- 71.67821549\, x_4 + 0.26110865\, x_1^2 + 0.000107516906\, x_2^2 - 0.00018413709\, x_3^2 \\
&+ 95.8001706\, x_4^2
\end{aligned} \tag{4.3}
$$

For uncoated carbide insert (CTW 4615):

$$
\begin{aligned}
&y'' = (1.1591 \times 10^4) x_0 + 9.9324 x_1 - 4.3265 x_2 + 0.8012 x_3 + 49.4129 x_4 \\
&- 1.8973 x_1^2 + 3.9917 \times 10^{-4} x_2^2 - 0.0012 x_3^2 - 34.1023 x_4^2
\end{aligned} \tag{4.4}
$$

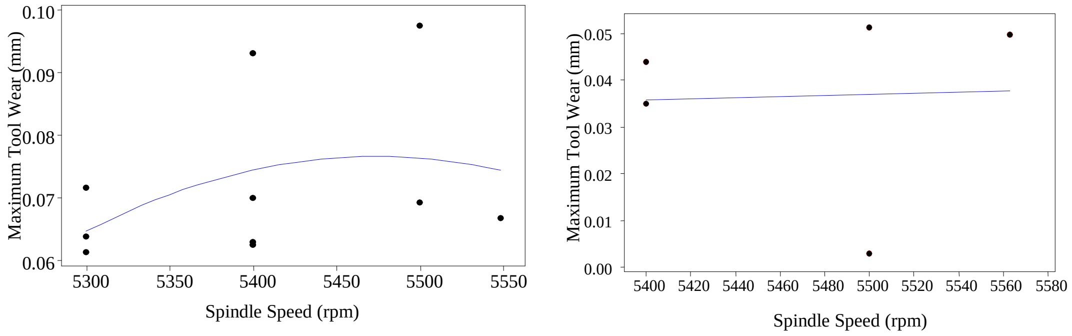
For coated carbide insert (CTP 2235):

$$
\begin{aligned}
&y'' = -34948.97167\, x_0 - 64.1178\, x_1 + 12.99725\, x_2 - 1.30283\, x_3 \\
&- 31.0227\, x_4 + 15.637454\, x_1^2 - 0.001194794892\, x_2^2 + 0.00157306764\, x_3^2 \\
&+ 45.69285047\, x_4^2
\end{aligned} \tag{4.5}
$$

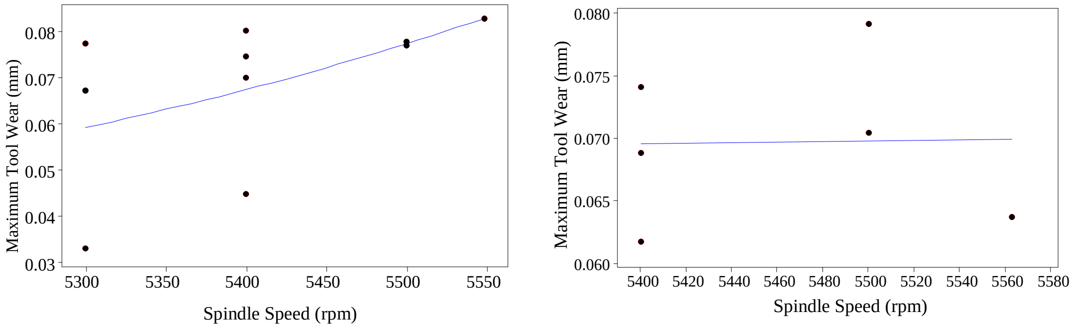
4.2.3 Progression Of Tool Wear

The variation of tool wear against spindle speed for flooded and MQL conditions are represented in Figure 4.1. As can be seen, the graph of tool wear are increasing as the spindle speed increases. This happens due to the increase in heat between the tool and the work piece, thus causing the tool to be vulnerable to damage. Besides the high frictional force between tool and work piece causes it to form rubbing marks which is also the beginning stage of flank wear. For coated carbide 2235, the value of maximum tool wear are similar to each other and both show an increasing result generally. For the coated carbide 1235 with MQL, it shows an obvious increase in tool wear as spindle speed increases but for flooded, the increase in tool wear are hardly can be seen. This could be due to feed rate which was set to minimum. The same trend of increasing tool wear with spindle speed shown by uncoated carbide 4615 for both MQL and flooded. For all the graphs, even though there is a difference in tool wear values, all the tool wear for both flooded and MQL are considered to be in safe range which is below 0.3 mm. This limit was selected based on criteria recommended by ISO 8688 (Kalidass et al., 2012). Based on the graphs, It can be seen that coated carbide 2235 would be suitable to be used under high spindle speed as the increase in tool wear is very low and the maximum tool wear are below 0.055 mm compared to other tools.

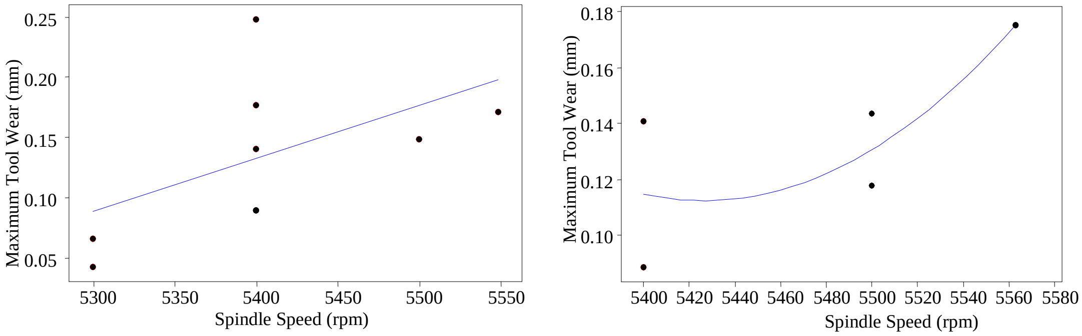
The effect of feed rate depends on other factors, mainly spindle speed. This is because feed rate and spindle speed involves movement which then decides the thermal barrier and frictional forces between tool and work pieces. According to Figure 4.2, most graphs are decreasing as the feed rate increases. For coated carbide 2235, MQL and flooded shows a decrease in the tool wear. Meanwhile, coated carbide 1235 MQL shows a decrease in tool wear but flooded shows an increase in the tool wear as the feed rate increases. Flooded coated carbide 1235, shows an increase only till 440 mm/min, then the tool wear tends to reduce. At 440 mm/min, tool wear seems high due to the high spindle speed which was set at 5500 rpm. On the other hand, uncoated carbide 4615 shows almost the similar result. For MQL, the graph increases and then reduces at feed rate of 380 mm/min. This happens due to the maximum spindle speed at that feed rate. Meanwhile, flooded for uncoated carbide 4615 shows a reducing trend. The results seems to be mostly reducing as the feed rate increase because of the contact time between tool and work piece.



(i) Coated carbide 2235



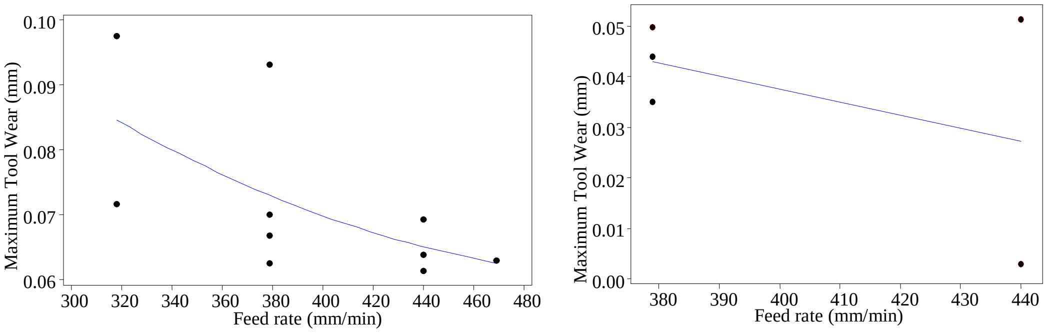
(ii) Coated carbide 1235



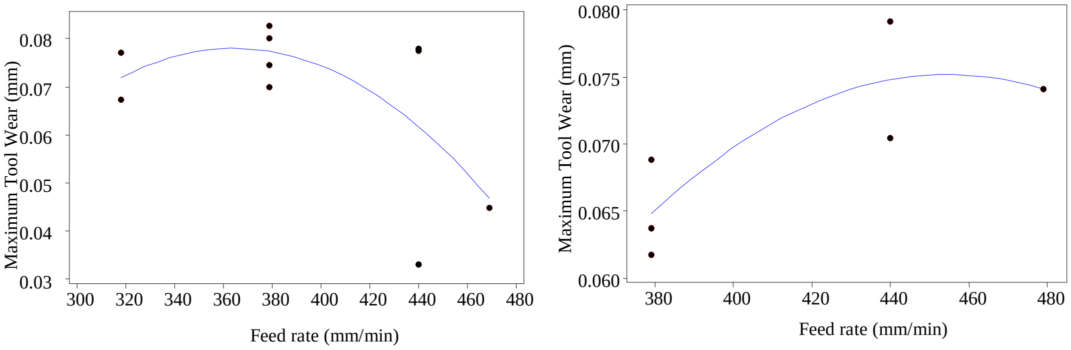
(iii) Uncoated carbide 4615

(a) MQL (b) Flooded

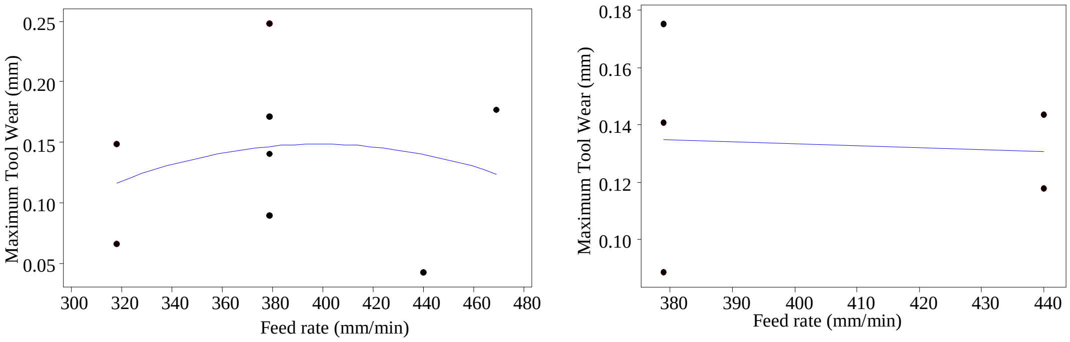
Figure 4.1: Variation of tool wear on spindle speed for MQL and flooded conditions.



(i) Coated Carbide 2235



(ii) Coated Carbide 1235



(iii) Uncoated carbide 4615

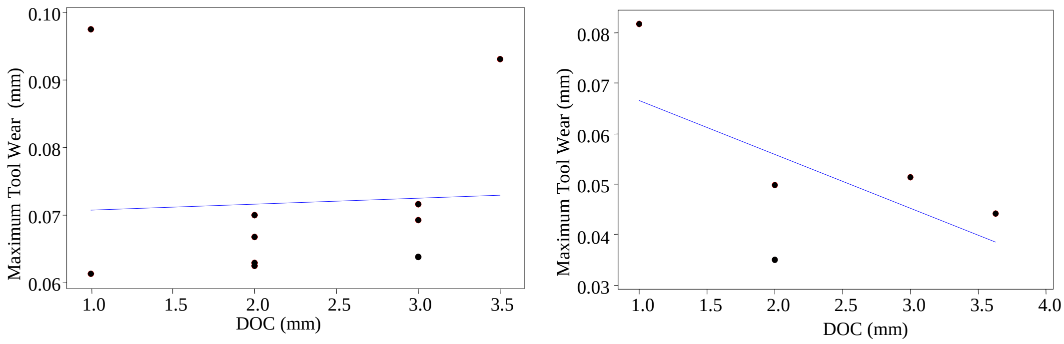
(a) MQL (b) Flooded

Figure 4.2: Variation of tool wear against feed rate for MQL and flooded conditions.

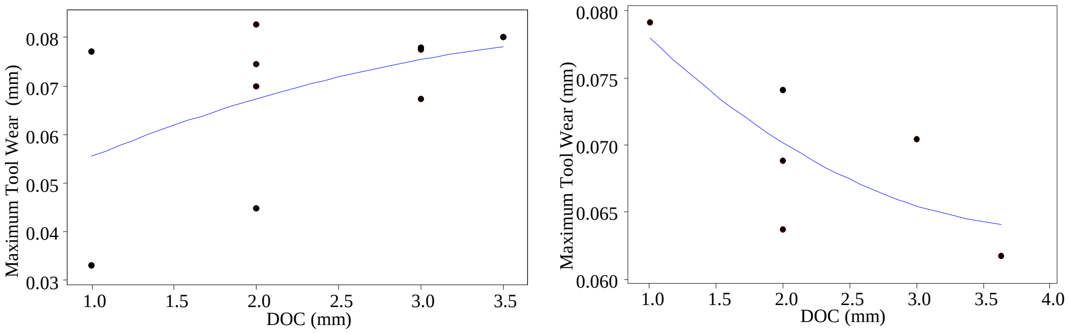
If the feed rate is too low, the time taken for a cut will be longer and thus increases the heat. This leads to damage on the tool. Therefore, using a high and optimum feed rate are recommended as it could reduce the tool wear and at the same time increases the material removal rate. Coated carbide 2235 for flooded shows a good trend compared to other tools as the decrease in tool wear is obvious and the maximum tool wear are below 0.05 mm. In term of MQL, coated carbide 2235 shows a good trend. Even though, the maximum tool wear is higher than that of MQL of coated carbide 1235, but the value are still below acceptable value of tool wear.

In term of depth of cut, tool wear are usually related to vibration on tools during the machining. In a previous research, it was shown that with increasing depth of cut, the tool wear decreases (Sivasakthivel et al., 2010). This is because, with more depth of cut, the tool tends to have less chatter vibration thus causing the propagation of tool wear to be in the steady region. Based on Figure 4.3, for coated carbide 2235, the tool wear seems to be increasing in a very lower rate for MQL and it directly reduces in flooded. Basically all the result of MQL shows a slight increase in tool wear. This could happen due to usage of minimum lubricant which less occupies the space between tool and work piece during machining. Unlike flooded which could cover all the area between tool and work piece thus reducing the frictional force and heat which could damage the tool. Coated carbide 4615 shows an increasing graph of tool wear against depth of cut. This could have happened due to minimum feed rate and high spindle speed at 3.63 mm depth of cut. Coated carbide 2235 and 1235 flooded shows a similar trend of decreasing tool wear with increasing depth of cut. This is because, it shows that the usage of MQL is sufficient for both of this coated for machining. With more MQL usage, the inserts tends to dissipate the heat easily through the lubricant. Thus both of this tool could be selected for machining Al6061-T6. Meanwhile, coated carbide 2235 shows a lower tool wear value and lower increasing rate of tool wear compared to other two tools.

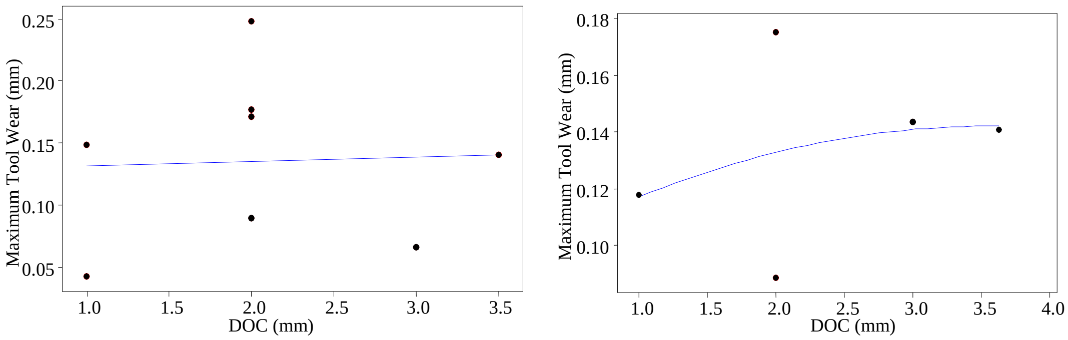
With more lubrication, the tool wear could be decreased. This is because, the lubricant acts as a cooling agent and reduces the temperature and frictional forces between inserts and tool wear (Su et al., 2006). Based on Figure 4.4, coated carbide 1235 shows a good result by using MQL. The tool wear decreases as the MQL flow rate increases and the tool wear shows the minimum value compared to other two tools. Figure 4.4 (i) shows a slight increase in tool wear as MQL flow rate increases. This could be affected by low feed rate, high spindle speed and low depth of cut which was selected at 0.0275 ml/min. It causes a high tool wear and thus causing the graph trend to be increasing slightly. Most tool wear are in acceptable region which is below 0.3 mm.



(i) Coated carbide 2235



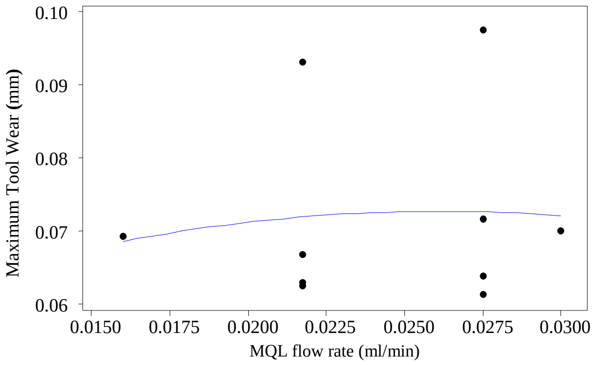
(ii) Coated carbide 1235



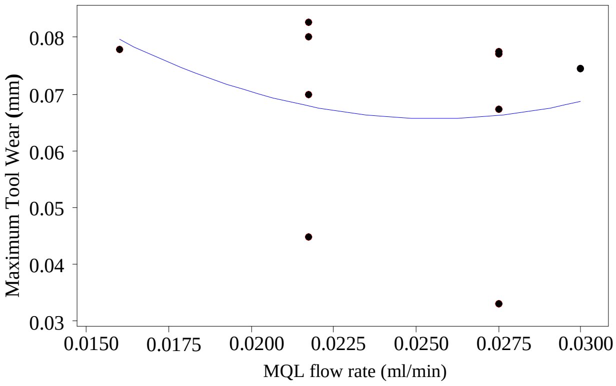
(iii) Uncoated carbide 4615

(a) MQL (b) Flooded

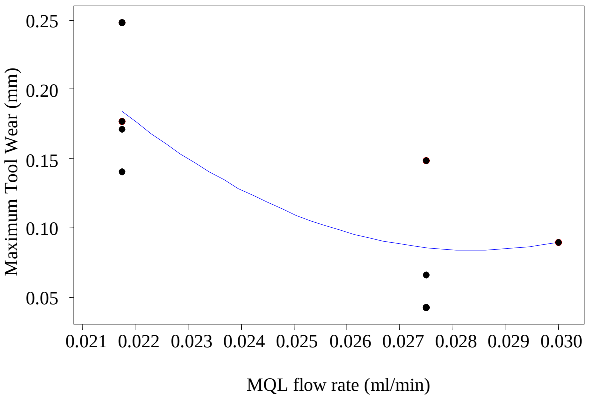
Figure 4.3: Variation of tool wear on depth of cut for MQL and flooded condition.



(i) Coated carbide 2235

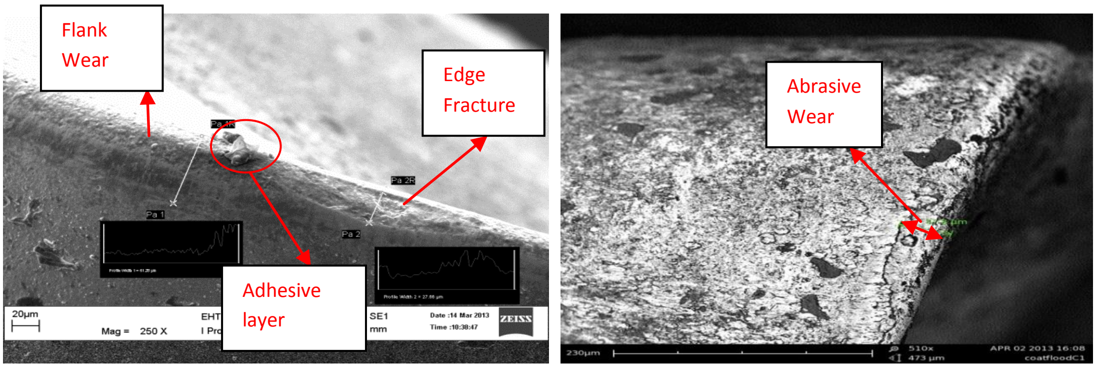


(ii) Coated carbide 1235

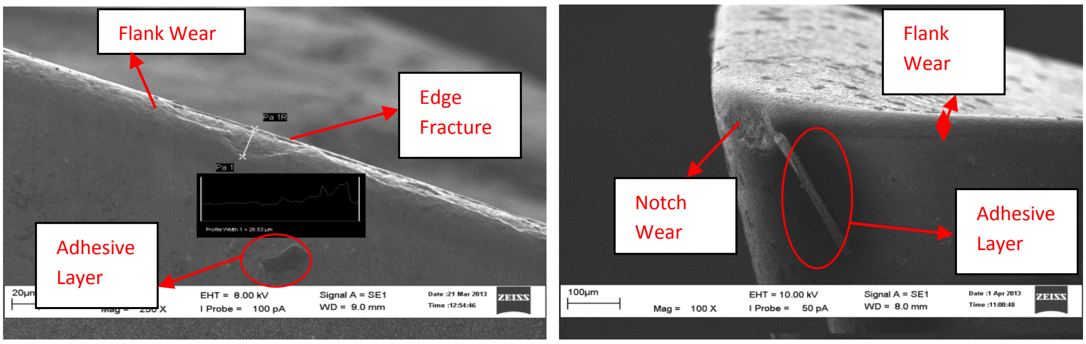


(iii) Uncoated carbide 4615

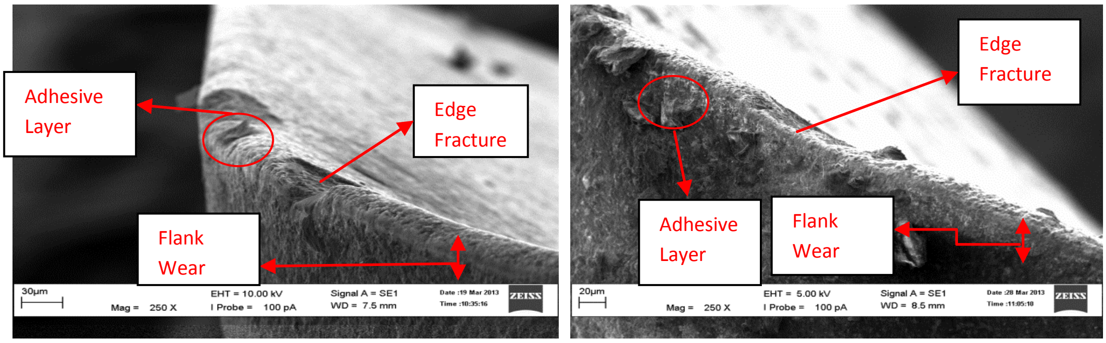
Figure 4.4: Variations of tool wear on MQL flow rate for different inserts.



(i) Coated carbide 2235



(ii) Coated Carbide 1235



(iii) Uncoated carbide 4615

(a) MQL (b) Flooded

Figure 4.5: Tool wear on different inserts for MQL and flooded conditions (i) coated carbide 2235; (ii) coated carbide 1235; (iii) uncoated carbide 4615.

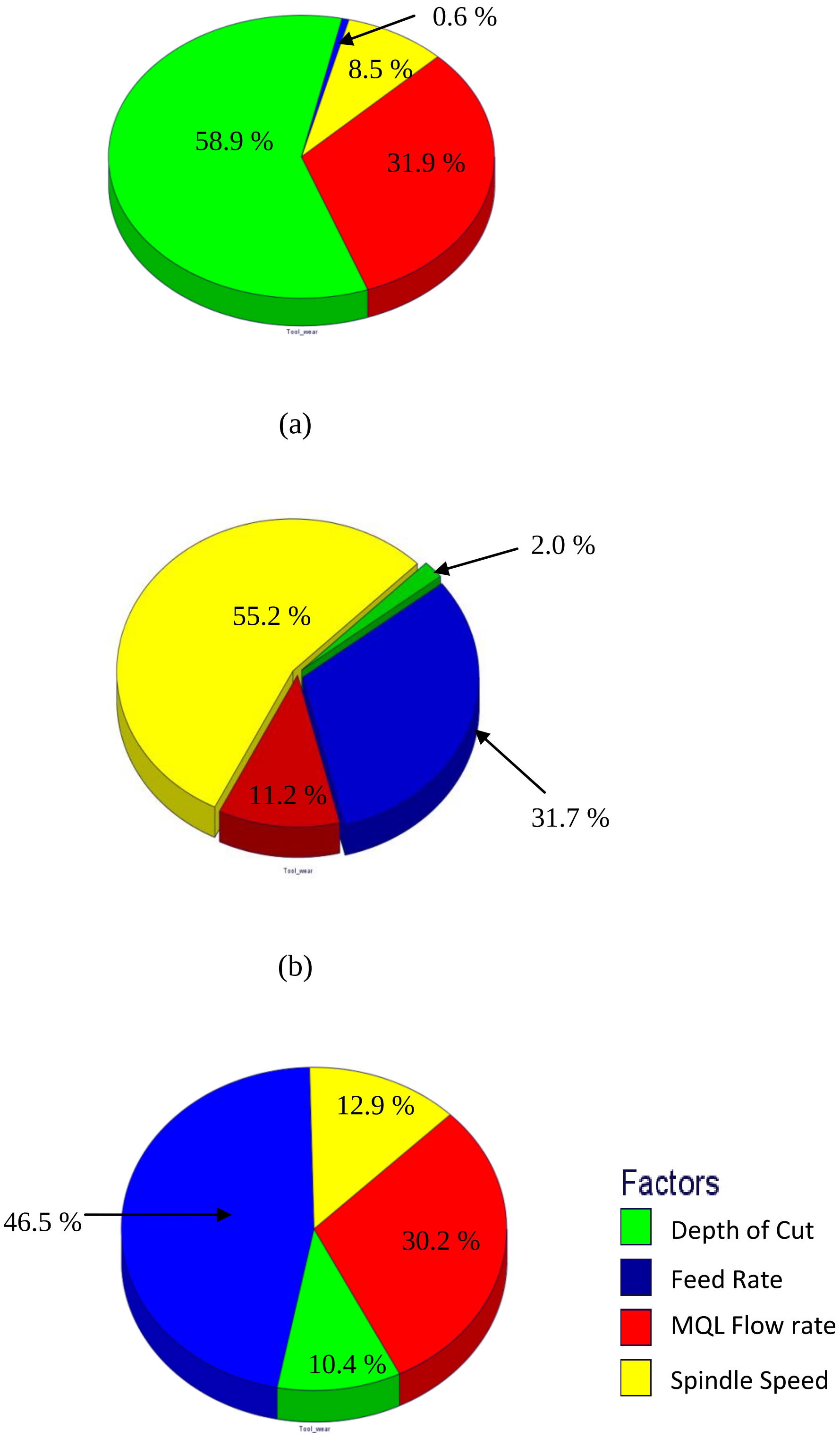
Figure 4.5 presents the characteristics of tool wear on different inserts for MQL and flooded cutting conditions. It can be seen that the most common tools wear in this study are the flank wear and adhesive layer. Flank wear usually happens on the relief part of insert and mainly occurs due to rubbing of inserts and finished work piece. Lubricants plays an important role in making sure that the friction force and resulting heat transfer is less and thus causing less flank wear to appear. However, appearance of flank wear is similar in both cases. It could lead to reduction in nose radius of the inserts when the amounts of flank wear increases. These affect the surface roughness of work piece. An increase in depth of cut affects the generation of adhesive layer due to more work piece surface contact towards the inserts. High temperature and high force are the main reason for adhesion (Kalidass et al., 2012). Adhesive layer on machined inserts can be reduced by using carbide coated inserts (Fontalvo et al., 2006). This study also shows that adhesive layer on uncoated carbide can be seen frequently compared to coated carbides. In this study, two different type of coated carbides were used which is titanium nitride (TiN) for coated carbide 1235 and titanium aluminum nitride (TiAlN) for coated carbide 2235. Damage such as edge fracture and nodge wear also could be identified on the inserts. The damage on flooded lubricants can be frequently seen in microstructure compared to MQL. However, the amount of adhesive layer on flooded inserts are less compared to MQL. The MQL lubricants are formulated with two major groups of additives; anti-wear additives and extreme pressure additives. When such lubricants are applied to the cutting zone, protective layers are formed on the interacting surfaces of the work piece and the cutting tool. These layers prevent direct contact between the tool and chip surfaces, and, therefore reduce friction forces and tool wear. In order to utilize MQL to its full potential, it is essential to select appropriate lubricant composition for particular work material and machining parameters.

4.2.4 Multi Objective Generic Algorithm

Based on the quadratic equations that was formed in Equation (4.3) - (4.5), a number of graphs were plotted to determine the effect of input parameter to tool wear. Design of experiment and tool wear values generated using multi objective generic algorithm shown in Table 4.3. To find the significance of each input parameters to tool wear, a pie chart was plotted. This will allow the user to identify the level of significance of each input parameters towards the tool wear and then further explain the corresponding values.

Table 4.3: Tool wear from multi objective generic algorithm.

Expt No.	**D.O.C (mm)**	**Speed (RPM)**	**Feed Rate (mm/min)**	**MQL flow rate (ml/min)**	**Tool Wear (µm)**		
					Uncoated 4615	**Coated 2235**	**Coated 1235**
1	3	5500	318	0.48	32.15	82.15	78.42
2	1	5300	440	0.825	19.03	62.99	41
3	1	5300	318	0.48	30.56	66.59	27.85
4	2	5400	379	0.9	28.10	71.54	79.9
5	2	5400	469.43	0.6525	93.63	64.54	44.84
6	3	5300	440	0.48	22.02	49.98	50.70
7	3	5500	318	0.825	33.85	92.02	96.82
8	1	5300	318	0.825	32.25	76.46	46.26
9	2	5548.26	379	0.6525	35.46	49.26	82.64
10	2	5400	288.56	0.6525	28.97	84.52	50.35
11	2	5400	379	0.39	20.62	57.30	56.75
12	3	5500	440	0.825	20.62	78.54	95.12
13	2	5251.74	379	0.6525	40.04	21.55	47.23
14	2	5400	379	0.6525	28.98	61.67	69.95
15	1	5500	440	0.825	15.94	81.68	70.57
16	3	5300	318	0.825	36.94	73.32	67.21
17	3.48	5400	379	0.6525	28.28	93.71	80.11
18	3	5300	318	0.48	35.25	63.46	52.40
19	1	5500	318	0.825	29.16	95.15	76.98
20	0.51	5400	379	0.6525	21.33	98.36	46.53
21	1	5500	440	0.48	14.24	71.81	52.17
22	1	5300	440	0.48	17.33	53.12	26.15
23	1	5500	318	0.48	27.47	85.28	53.87
24	3	5500	440	0.48	18.93	68.67	77.76
25	2	5400	379	0.6525	28.98	61.67	64.15
26	3	5300	440	0.825	23.72	59.85	77.37



(a)

(b)

(c)

Figure 4.3: Significance of input parameter in tool wear on (a) coated carbide 1235, (b) coated carbide 2235 and (c) uncoated carbide 4615.

Figure 4.6 shows the significance of each input parameter to tool wear. From Figure 4.6 (a) it can be seen that depth of cut plays an important role in determining the tool wear rate followed by MQL flow rate. Lubrication is important to cool down the insert especially at the contact surface. The feed rate and spindle speed has less role in tool wear generation for coated carbide 1235. According to Figure 4.6 (b), spindle speed has a high significance on the tool wear of coated carbide 2235. It has 55.2 % significance on it which is more than half. This is followed by feed rate, MQL and depth of cut with 31.7 %, 11.2 % and 2 % accordingly. The lowest significance on tool wear of this coated carbide 2235 are depth of cut which shows a near to negligible result. Based on Figure 4.6 (c), feed rate and MQL flow rate shows the highest significance on tool wear for uncoated carbide 4615 compared to other 2 input parameters with a percentage of 46.5% and 30.2 % respectively.

Based on Figure 4.7, uncoated CTW 4615 shows tool wear increases as the spindle speed increases. As the spindle speed increases, the frictional force between tool and work piece increases and thus causes the tool to wear. At the same time, the heat transfer between work piece and tool also increases, which then leads to severe damage. Coated CTP 1235 shows a very less increment in tool wear as the spindle speed increases. This could have happened due to the resistance of coated insert to tool wear. Even though the increment is less, but it still shows a higher amount of tool wear compared to uncoated CTW 4615. This might be due to the rigidity of uncoated carbide which is not coated with any chemicals. The failure of bonding between coating and insert also could support tool wear to happen. Most highest amount of tool wear in Figure 4.7 is shown by coated CTP 2235. This happens due to the increase in heat transfer between tool and work piece during machining. With increase in heat, the coatings will begin to expand and thus start to peel off from the carbide insert. The maximum amount of tool wear is 80 µm by coated CTP 2235 and the lowest is by uncoated 4615 which is 18 µm only. Therefore, uncoated CTW 4615 can be recommended to be used under high speed machining conditions.

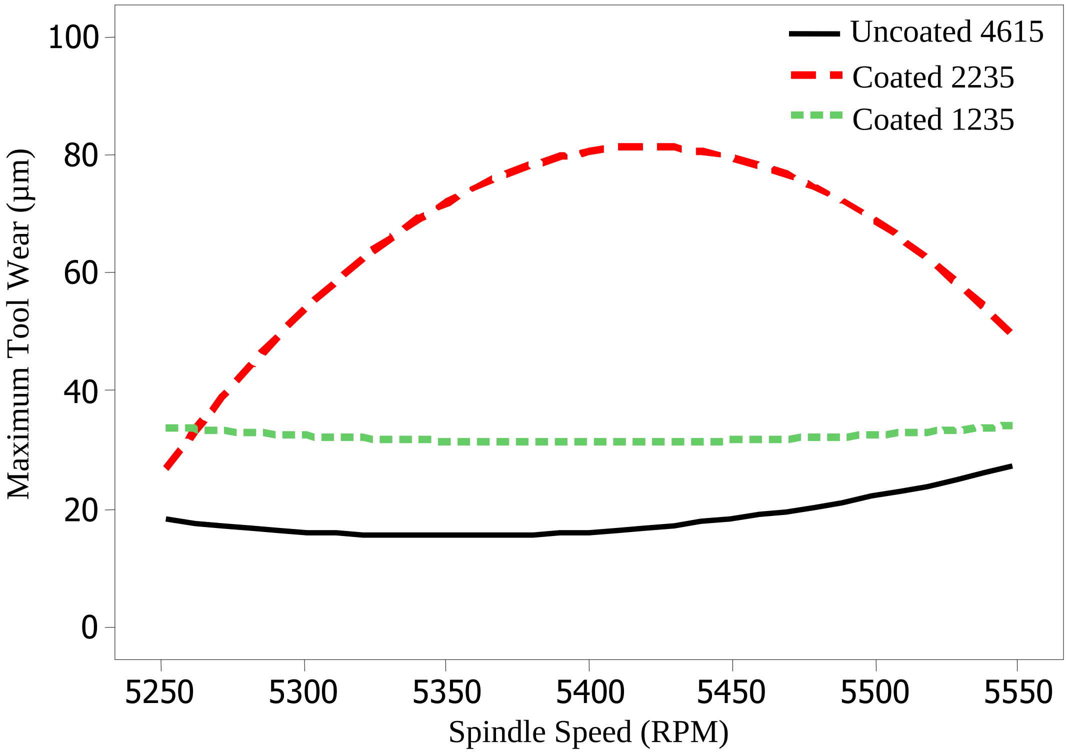


Figure 4.7: Tool wear versus spindle speed for coated CTP 2235, coated CTP 1235 and uncoated CTW 4615.

Another factor that affects tool wear is feed rate as illustrated in Figure 4.8. It can be seen from the graph that the tool wear for uncoated CTW 4615 generally decreases as the feed rate increases. This happened due to the time of contact between tool and work piece. At higher feed rate, the work piece tends to be machined faster thus resulting in reduced heat. Besides, there is always vibration during machining. Fast machining could reduce vibration by reducing the contact time. External vibration such as from machine itself could cause the tool damage when it fails to cut under a steady condition. Besides, this could also cause higher surface roughness on work pieces. Coated CTP 1235 shows a very less decrease in tool wear as the feed rate increases. However, coated CTP 2235 tends to decrease drastically with increasing tool wear. Higher feed rate causes the contact time between tool and work piece to be shorter thus reducing heat produced on to the tool. After 418 mm/min, the tool wear slightly increases. This could have happened due to coatings on carbide tool which is not strong enough for higher feed rate. At higher feed rate, the surface roughness produced is not very smooth and therefore, the rough surface of workpiece could affect the coating of carbide tool to peel off. From figure 4.8, highest amount of tool wear is achieved by coated 2235 which is 85 µm and the lowest tool wear is uncoated CTW 4615 with 17 µm of tool wear at higher feed rate. Therefore, uncoated carbide shows a good property for machining under high feed rate.

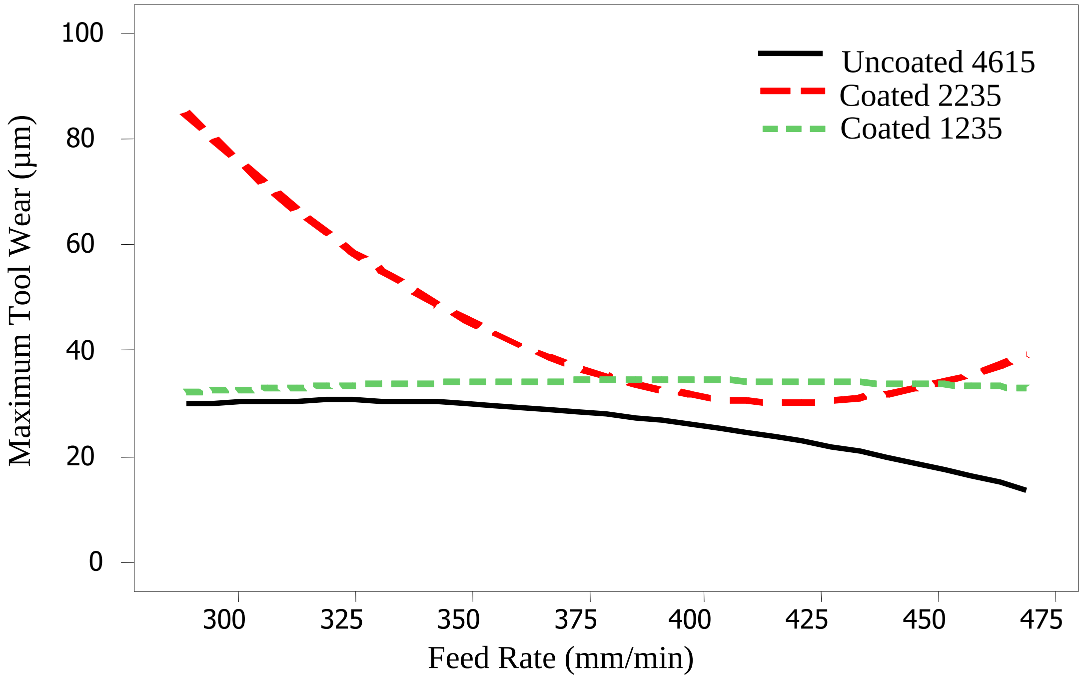


Figure 4.8: Tool wear versus feed rate for coated CTP 2235, coated CTP 1235 and uncoated CTW 4615.

From Figure 4.9, it can be said that with increase in depth of cut, the tool wear decreases for uncoated 4615. This could have happened due to the decrease in vibration during machining. With increase in depth of cut, the tool tends to have higher stability. Vibration of machine will not give much effect as the tool is stable at higher depth. Tool wear increases as the depth of cut increases for coated CTP 1235. This happens because, with increasing depth of tool in work piece, the amount of surface in contact increases, thus leads to increase in heat during machining. Abrasive wear marks will begin to appear in this situation and at the same time it will form more adhesive layer as the contact surface is more. Since CTP 1235 is chemically coated, it could be affected by high increase in heat and friction. For coated 2235, tool wear decreases as the depth of cut increases. Then tool wear tends to increase starting from about 2.1 mm depth of cut. At minimum value of depth of cut, the tool wear seems to be high. This probably could be due to the vibration of spindle which causes the tool not to be able to cut the work piece properly and caused damage on it. With less depth of cut, tool will have more vibrations. As the depth of cut increases till 2.05 mm, the tool wear seems to be reducing, this could be the stable position of the tool to have less vibration. After 2.05 mm depth of cut, the tool wear tends to increase. This could have happened due to the amount of heat transfer on the tool which increases increasing amount of tool surface that is in contact with the work piece. It can be concluded from Figure 4.9 that the best insert for cutting under higher depth of cut is uncoated CTW 4615 since the lowest tool wear achieved is 15 µm. Meanwhile, coated CTP 2235 shows a very high tool wear which is 82 µm at lowest depth of cut and 78 µm at higher depth of cut.

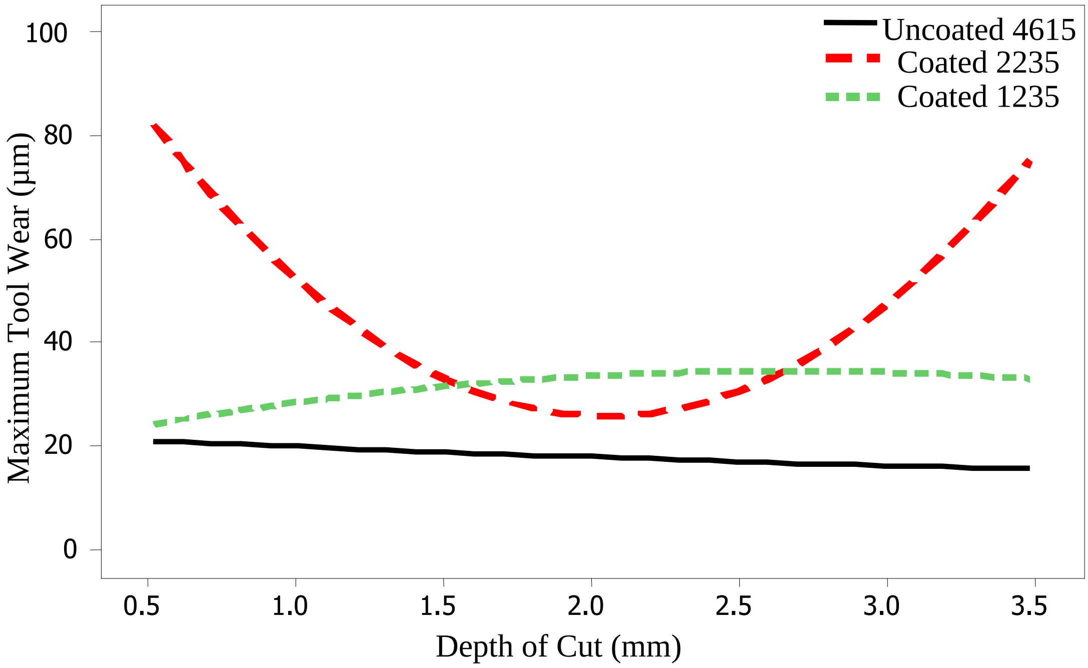


Figure 4.9: Tool wear versus depth of cut for coated CTP 2235, coated CTP 1235 and uncoated CTW 4615.

According to Figure 4.10, tool wear of coated CTP 1235 and uncoated CTW 4615 shows a similar trend of increase in tool wear as the MQL flow rate increases.

This might happened because the amount of lubricant is not suffice for the cutting process until it reaches 0.72 ml/min. Maximum tool wear of 32 µm were achieved at MQL flow rate of 0.72 ml/min for coated CTP 1235. And the maximum tool wear for uncoated CTW 4615 is 22 µm. Meanwhile, coated CTP 2235 shows a decrease in tool wear as the MQL flow rate increases. This is due to the fact that lubricants helps to reduce the friction and heat transfer between tool and work piece. Therefore in this study it is recommended to use the coated CTP 2235 since the tool wear decreases at higher MQL flow rate. However, at lower MQL flow rate, uncoated CTW 4615 can be used since the tool wear shows the most minimum among the other 2 inserts.

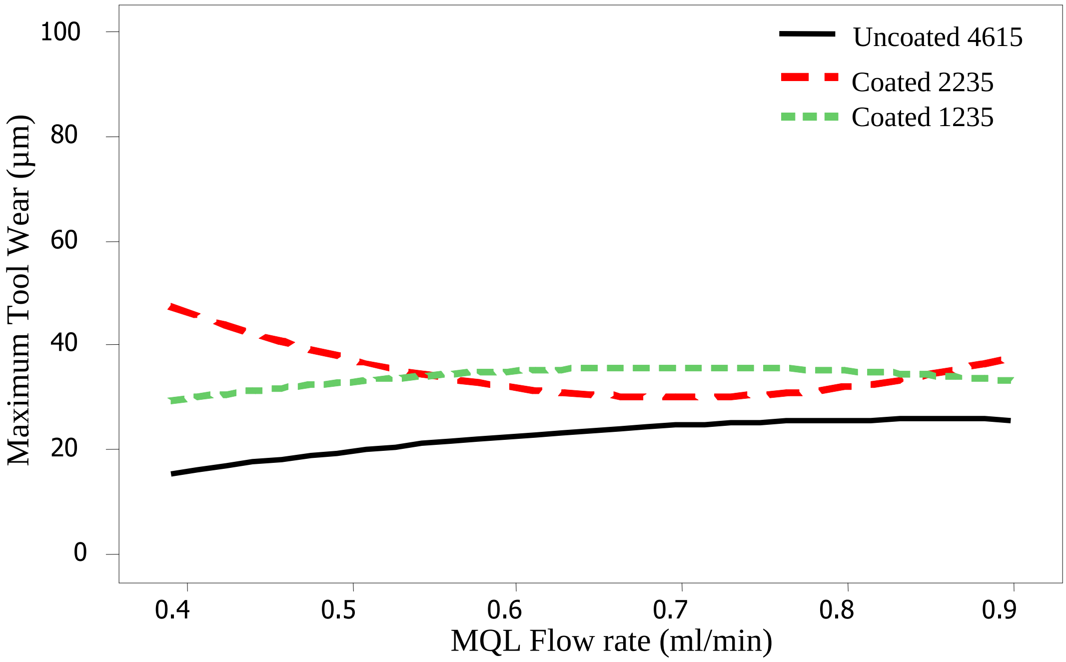


Figure 4.10: Tool wear versus MQL flow rate for coated CTP 2235, coated CTP 1235 and Uncoated CTW 4615.

4.2.5 Optimization of Machining Parameters for MQL

Based on the study, an optimized value of input parameters were found by using multi criteria decision maker (MCDM). Achieving minimum material removal rate, maximum surface roughness and minimum tool wear are one of the objectives of this study. Table 4.7 shows the optimized parameters.

Table 4.4 shows the optimum values for each type of inserts. The material removal rate shows the maximum values meanwhile, the surface roughness and tool wear shows a minimum value. From these optimum results, it can be seen that uncoated carbide shows a good outcome of machining. Even though the surface roughness produced is slightly higher compared to coated carbide, but the amount of tool wear are less compared to other coated carbides and the material removal rate are higher too.

Table 4.4: Optimized values for each input and output parameters.

Types of Insert	Depth Of Cut (mm)	Spindle Speed (rpm)	Feed Rate (mm/ min)	MQL Flow rate (ml/ min)	Material Removal Rate (mm^3/ min)	Surface Roughness (µm)	Tool Wear (µm)
Uncoated Carbide 4615	3.096	5291.8	463.5	0.390	15398.0	0.631	14.25
Coated Carbide 2235	2.556	5251.7	432.7	0.662	13936.6	0.636	24.43
Coated Carbide 1235	2.724	5251.7	451.5	0.841	14289.9	0.401	26.26

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 INTRODUCTION

This chapter finalize the important results of the from this study. This study has come up with a several models to predict the tool wear of coated and uncoated carbides due to machining aluminum alloy 6061-T6. Apart from that, it has been stressed that this study mainly concentrates on MQL lubrication and its effect on machining parameters. Several recommendations and suggestions has been provided for future research in this field.

5.2 SUMMARY OF FINDINGS

This study has mainly used response surface method to develop mathematical models. This study has used multi objective optimization to solve and to find the best input and output parameters. Based on this study, uncoated and coated carbides have played an important role in machining aluminum alloy 6061-T6. The introduction of MQL into this study also has been a challenge especially when some of the results seems to deviate compared to using flooded. With the optimization done, it can be concluded that uncoated carbide shows a good machining properties. Tool wear are less detected in uncoated carbide 4615 compared to coated ones. This could have happened due to the introduction of MQL. With MQL, uncoated carbide seems to be more rigid but both coated carbide showed a comparably higher results. The material removal rate and surface roughness was taken into consideration in this study. Thus, from the overall optimization data, uncoated carbide had less tool wear, more material removal rate and slightly higher surface roughness compared to coated

1235. By using MQL, it can be seen that the results of tool wear are comparative to flooded. The tool wear does not show much changes. Besides, all the values are in the acceptable range, which are below 0.3 mm. Therefore, this study shows that usage of MQL in aluminum alloy 6061-T6 are effective and can be encouraged.

5.3 RECOMMENDATION FOR FUTURE WORK

In near future, the introduction of nano-fluid lubricants are trending. Therefore, the effect of nano-fluid lubrication towards the end milling machine characteristics can be studied. Besides, it can be further upgraded to hybrid nano-fluid lubrication too with the same objectives. Then, this effect can be compared with the usage of MQL. Besides, in future, the effect of vibration from machine on machining parameters can be studied.

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I certify that the project entitled “Experimental Investigation Of Minimum Quantity Lubrication On Tool Wear In Aluminum Alloy 6061-T6 Using Different Cutting Tools” is written by Puvanesan A/L Muthusamy. I have examined the final copy of this project and in my opinion, it is fully adequate in term of language standard and report formatting for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering.

(Mr. SAIFUL ANWAR CHE GHANI)
Examiner Signature

EXPERIMENTAL INVESTIGATION OF MINIMUM QUANTITYLUBRICATION ON TOOL WEAR IN ALUMINUM ALLOY6061-T6 USING DIFFERENT CUTTING TOOLS

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