DRY MACHINING AND MINIMUM QUANTITY LUBRICANT OF ALUMINUM ALLOY 6061-T6 USING COATED CARBIDE TOOLS

NUR AMIRRA BINTI RASHID

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ABSTRACT

This report describes the cutting performance of different coated carbide cutting tools on surface roughness during machining of aluminum alloys AA6061-T6 using dry machining and minimum quantity lubricant (MQL) technique. The cutting speed, depth of cut and feed rate were the selected input parameters in this study. This experiment was conducted based on central composite design (CCD) method. To develop a model of process optimization based on the response surface method. The investigation results showed that MQL technique lowers the surface roughness values compared with that of conventional dry cutting conditions. Based on the investigations of the surface roughness conditions and material removal rate, MQL technique reduces the cutting temperature to some extent. This caused the surface roughness value to lower while dry machining is dependent on the heat to get better surface roughness result. In summary, the improvement in surface finish is achieved utilizing higher feed rate, medium depth of cut, lower speed and lower MQL flow rate.

ABSTRAK

Laporan ini menerangkan prestasi pemotongan yang berbeza karbida bersalut memotong alat kepada kekasaran permukaan semasa pemesinan aloi aluminium AA6061-T6 menggunakan mesin kering dan pelincir kuantiti minimum (MQL) teknik. Kelajuan pemotongan, kedalaman pemotongan dan kadar suapan adalah parameter input yang dipilih dalam kajian ini. Eksperimen ini telah dijalankan berdasarkan reka bentuk komposit pusat (CCD) kaedah. Untuk membangunkan model pengoptimuman proses berdasarkan kaedah gerak balas permukaan. Hasil siasatan menunjukkan bahawa teknik MQL merendahkan nilai kekasaran permukaan berbanding dengan keadaan memotong konvensional kering. Berdasarkan siasatan keadaan kekasaran permukaan dan kadar pembuangan bahan, teknik MQL mengurangkan suhu pemotongan sedikit. Ini menyebabkan nilai kekasaran permukaan yang lebih rendah manakala pemesinan kering adalah bergantung kepada haba yang lebih baik hasil kekasaran permukaan. Secara ringkasnya, peningkatan dalam kemasan permukaan dicapai menggunakan kadar yang lebih tinggi makanan, kedalaman sederhana potongan, kelajuan yang lebih rendah dan kadar aliran MQL lebih rendah.

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LIST OF SYMBOLS/ ABBREVIATIONS

N	Rotational speed of the work piece
f	Feed
v	Feed rate, or linear speed of the tool along work piece length
V	Surface speed of work piece
l	Length of cut
Do	Original diameter of work piece
Df	Final diameter of work piece
Davg	Average diameter of workpiece
d	Depth of cut
t	Cutting time
Ra	Average deviation of mean surface
Rt	Maximum roughness height
Rz	Root mean square value
SFPM	Surface feet per minute
MRR	Material removal rate
MQL	Minimum Quantity Lubricant

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

End milling is one of the most widely used metal removal operations in industry because of its ability to remove material faster giving reasonably good surface finish, as stated by Lakshmi and Venkata (2012). End mills are used for producing precision shapes and holes on a milling or turning machine. The end mills are a metal removal procedure that is achieved by feeding a work piece into a revolving cutter. The cutter is removed matter as chips. The correct selection and use of end milling cutters is dominant with either machining centers as stated by Kouam et al. (2012). In industry where usually, in high-volume production, machining parameters made impacts on the machine performance in terms of productivity which is cycle time, tool life, and product quality which involves surface finish (Rao and Vimal, 2012). There are generally three types of conditions during end milling machining, where the machining is classified as dry machining, semi-dry machining and wet machining. The dry condition happens where there is no lubrication used throughout the process but for semi-dry, the usage of minimum quantity lubrication is practiced during the machining process and as for wet machining, the flooded lubrication usage is used in the duration of machining operations (Klocke and Eisenblatter, 1997).

Yamamoto et al. (2003) has stated that the dry machining may expose machine operators to increased levels of dust, since it is assumed that use of metalworking fluids helps contain machining dust. Therefore, in machining processes, such as milling, grinding, turning, boring, and drilling, the operators usually rely on the use of metalworking fluids to transfer heat from the cutting zone, lubricate the chip-tool interface, flush away chips, and inhibit corrosion. The lubrication fluid used during wet machining can cause several harm to humans and environment. As such, the necessity to machine using less harmful cutting fluids has prompted many researchers to investigate the use of minimum quantity lubrication (Boubekri and Vasim, 2012). By using the less harmful cutting fluid, the hazard level in workplaces can be reduced and a safer environment can be created. Both the minimum quantity lubrication and dry machining research and practice is moving forward for two major reasons; the potential reduction in cost by minimizing or eliminating the use of cutting fluids which are expensive to use and maintain, the health and environmental benefits of minimizing metalworking fluid usage, termed "green machining" (Yamamoto et al. 2003). Hence, this project is aimed to investigate on the dry machining and minimum quantity lubrication of aluminum alloy 6061T6 using coated-carbide tools. The CNC end milling machine has been selected for conducting the milling action on the specimen.

1.2 PROBLEM STATEMENT

Boubekri and Vasim (2012) stated that the amounts of metal working fluid may contribute to adverse health effects and safety issues, including toxicity, dermatitis, respiratory disorders and cancer. The mechanical infrastructure that sustains a flood coolant system is of such complexity that it hinders the rapid reconfiguration of equipment. In the conventional application of flood coolant, the chips produced are wet. They have to be dried before recycling, which incurs additional cost (Mathew et al.,2010). The lubricants used during flooded machining tend to raise problems to human health, the equipment usage and proven to be quite costly. This is where minimum quantity lubricant's idea comes off and various research have been conducted in order to overcome the weaknesses during flooded machining where the excessive amount of the lubricant itself proven to be hazardous to mankind and environmental alike (Brian and Islam, 2012).The excessive amount of lubrication usage has also hinder the reconfiguration of equipments used during machining operations and by using large amount of cutting fluid, the cost will increase drastically.

In machining, it is important to be very careful in selecting certain machining parameters that will be used. Selecting the wrong choice of parameters for dry machining and amount of lubricants for each material may lead to the high maintenance cost of the machine, poor surface finish of the work pieces, shorter tool life, low production rate, material waste and it will also increase the production cost of the said process. In this study, the main objective is to observe whether the chosen cutting parameters will affect the surface roughness of the specimen, Aluminum alloy 6061-T6, in both dry and minimum quantity lubricant machining. Because of that, the parameters are being controlled and adjusted to provide the best surface roughness. The surface roughness, tool life and material removal rate of both dry machining and minimum quantity lubricant machining, using the same cutting parameters, are obtained and being compared as to get the optimum result.

1.3 OBJECTIVES OF THE PROJECT

The objectives of this project are as follows:

i. To determine the surface roughness and material removal rate of aluminum alloy 6061-T6 using coated-carbide tools in dry machining and minimum quantity lubrication.
ii. To determine the optimum cutting parameters for dry machining and minimum quantity lubrication processes.

1.4 SCOPE OF THE PROJECT

The scopes of this project are as follows:

i. The HAAS VF6 CNC end milling center machine is used to conduct end milling operation on aluminum alloy 6061-T6 specimen with the dimension (100 × 100 × 30) mm with the usage of coated carbide tool under dry machining and minimum quantity lubrication condition.

ii. Determining the optimum cutting parameters with the cutting speed, feed rate and depth of cut are being controlled.

iii. Prepare the design of experiments in order to state the relationship between cutting parameters and surface roughness.

iv. ANOVA analysis is performed to check the adequacy of the experiment data for analysis.

v. Mathematical model is developed using response surface method.

1.5 ORGANIZATION OF REPORT

This report was prepared with sufficient information based on 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 modeling. Meanwhile, Chapter 3 discusses the design of experiment, preparation of experimentation, mathematical modeling techniques and statistical methods. In Chapter 4, the important findings are presented in this chapter. Chapter 5 concludes the outcomes of this study and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides the review from previous research efforts related to dry machining and minimum quantity lubrication of aluminum alloy 6061-T6 using coated-carbide tools. In today's modern society, machining industries are focusing on achieving high quality of products and high production rate. In machining, a good quality product must be able to satisfy the dimensional accuracy of the work piece, a good surface finish, less wear on cutting tools, cost-saving and environmental friendly. Substantial literature has been studied on machinability of aluminum alloys which is covers on surface roughness, tool life, tool wear cutting force. This review has been well elaborate to cover different dimensions about the current content of the literature, the scope and the direction of current research. This study has been made in order to help identify proper parameters involved for this experiment. The review is fairly detailed so that the present research effort can be properly tailored to add to the current body of the literature as well as to justify the scope and direction of present.

2.2 DRY MACHINING

Dry machining is desirable and it will be considered as an essential for manufacturing industries in the future. Industries will be forced to consider dry machining to enforce environmental protection laws for occupational safety and health regulations (OSHA) as stated by Matthew et al. (2010).The advantages of dry machining include some reward such as non-pollution of the atmosphere and water; less to no residue on the swarf which are reacted in reduced disposal and cleaning costs; did not pose danger to health; and it is non-injurious to skin and is allergy free as stated by Brian and Islam (2012). Moreover, it offers cost diminution in machining (Asthakov, 2008). Although the good performance of dry machining process has been proven, a big problem is still present where the tool wear under severe conditions which sometimes need the use of a little amount of lubrication fluid. Recently, the scientists had found that dry machining requires a very hard tool material that can withstand the high temperature during the machining processes written by Sanjit et al. (2010) They also found that tool life in dry machining could be similar in lubricated machining, which the tool life increased, if the cutting depth is fewer with high cutting speed. Some personnel even developed a method or technique using small lubrication fluid in machining process as stated by Kouam et al. (2012)

2.3 MINIMUM QUANTITY LUBRICANT

Cutting fluids commonly known as lubricants are being used widely in machining to reduce friction, cool and reduce the temperature of the work piece, and wash away the chips that formed during machining process as written by Ibrahim et al. (2009). With the application of cutting fluid, the tool wear decreased rapidly and machined surface quality improves. In many circumstances, the cutting fluids also act as a defensive layer to protect the machined surface from corrosion. They also minimize the cutting forces thus saving the energy usage. These advantages of using cutting fluids in machining come with a number of drawbacks. Sometimes the cutting fluid costs are more than twice the tool-related costs as stated by Astakhov (2008). There are foremost two types of cutting fluids used in machining. The first is neat oils or straight cutting oils while the second is water-mix fluids as stated by Kelly and Cotterell (2002). Neat oils are based on mineral oils and used for the metal cutting without further dilution, meaning there are no water-added. They are generally blends of mineral oils and other additives. The most commonly used additives are fatty materials, chlorinated paraffin, sulfurized oils, and free sulfur.

Kovacevic et al. (1995) studied the performance of a face milling process, in which a high pressure water jet was delivered into tool–chip interface through a hole in the tool rake face. The authors shown that surface finish produced is of good quality by using the pressured water jet. Weinert et al. (2004) have presented an excellent review of dry machining and minimum quantity lubrication (MQL). The cutting oil can be sent with air in the form of aerosol or without air as shown in Figure 2.1, where the minimum quantity lubrication typical application with 3 nozzles is used where the normal usage rate of cutting fluid medium is 5–50 ml/min. (Koavevic et al. 1995). The supply of cutting fluid can be external (through nozzles) or internal (through a channel) in tool. There can be a single channel system or double channel system, in which the air and oil are fed separately. In many cases, it provides improved performance than conventional flood coolant system. When machining aluminum alloys, Kelly and Cotterell (2002) observed that as cutting speed and feed rate are increased, the use of a fluid mist outperformed the conventional flood coolant method, however, at lower cutting speed flood coolant system was better. It is observed that the use of cutting fluids improves the surface finish, which is attributed to the reduction in the coefficient of friction as well as the size of the built up edge. Furthermore, fluid penetration into the cutting interface reduces adhesion between the tool face and the chip through a chemical reaction, which therefore depends on the surface speed as stated by Koavevic et al. (1995). Hence, cutting fluids are more effective at lower surface speeds.

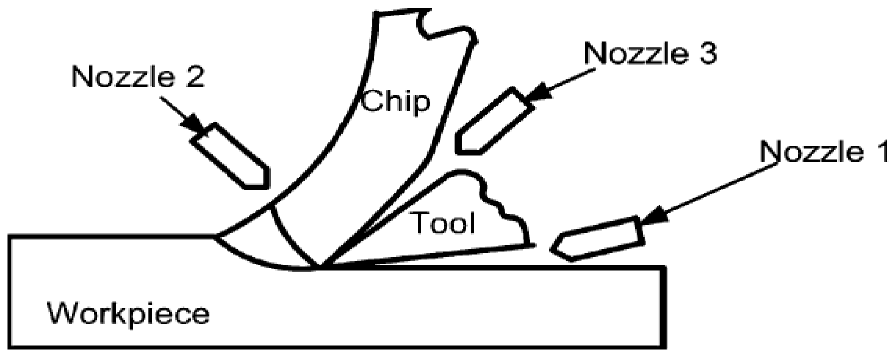

Figure 2.1: MQL typical application with 3 nozzles.

Source : Koavevic et. al. (1995)

2.4 CNC END MILLING MACHINE

CNC stands for computer numerically controlled. As a milling technique, this means that a design can be specified on a computer using CAD tools, and that a computer can handle the milling process. CNC machines are considered most suitable in flexible manufacturing system. CNC milling machine is very useful for both its flexibility and versatility. These machines are capable of achieving reasonable accuracy and surface finish as stated by Matthew et al. (2010). Processing time is also very low as compared to some of the conventional machining process. On the other hand, material removal rate which indicates processing time of the work piece, is another important factor that greatly influences production rate and cost. Therefore, there is a need for a tool that should allow the evaluation of the surface roughness and material removal rate value before the machining of the part and which can easily be used in the production-floor environment contributing to the minimization of required time and cost and the production of desired surface quality according to Songmene et al.(2011). Both the surface roughness and material removal rate greatly vary with the change of cutting process parameters. That is why proper selection of process parameters is also essential along with the prediction of the surface finish (lower Ra value) and material removal rate in CNC end milling process (Ishanet al. 2012).

2.5 CUTTING PARAMETERS

In general, it is found that surface roughness increases with an increase in the feed rate and depth of cut and a decrease in cutting speed according to Sasimurugan and Palanikumar (2011). Roughness is found to reduce drastically up to a particular critical value of surface speed which is attributed to the reduction in size of the built up edge as stated by Lakshmi and Venkata (2012). At this speed, when the effect of the built up edge is considered negligible, the profile of the cutting edge of the tool (pointed or curved) gets imprinted on the work surface, and the surface roughness from this point on depends on the feed rate.

2.5.1 Cutting Speed

Cutting speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (RPM), it tells their rotating speed. Cutting speed is the speed of the work piece surface relative to the edge of the cutting tool during a cut, measured in surface feet per minute. Spindle speed is the rotational speed of the spindle and the work is in revolutions per minute as stated in Equation (2.1). The spindle speed is equal to the cutting speed divided by the circumference of the workpiece where the cut is being made. In order to maintain a constant cutting speed, the spindle speed must vary based on the diameter of the cut. If the spindle speed is held constant, then the cutting speed will vary.

$$RPM \quad = \frac{CuttingSpeed \times 4}{DiameterofCutter} \tag{2.1}$$

2.5.2 Feed Rate

Feed rate are the movement of the tool in relation to the revolving work piece. The units for the feed rate are millimeter per revolution (mm/rev). It is a major factor that has a direct impact on surface roughness as stated by Vikram and Ratnam (2012). Feed rate is defined by the speed of the cutting tool's movement relative to the workpiece as the tool makes a cut. The feed rate is measured in inches per minute and is the product of the cutting feed (IPR) and the spindle speed. Cutting feed is the distance that the cutting tool or work piece advances during one revolution of the spindle, measured in inches per revolution. In some operations the tool feeds into the work piece and in others the work piece feeds into the tool. For a multi-point tool, the cutting feed is also equal to the feed per tooth, measured in inches per tooth, multiplied by the number of teeth on the cutting tool.

2.5.3 Depth of Cut

Axial depth of cut is the depth of the tool along the axis of the work piece as it makes a cut, as in a facing operation. A large axial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life in accordance to Sanjit et al. (2010). Therefore, a feature is typically machined in several passes as the tool moves to the specified axial depth of cut for each pass. A larger depth of cut, or in other words a larger chip cross-sectional area adversely affects surface finish though it is usually not significant until it is large enough to cause chatter. The effect of increased feed is more pronounced on surface finish than the effect of an increased depth of cut. Thus, measures for improving machining productivity (increasing feed and depth of cut) work against achieving better surface quality.

2.6 OUTPUT PARAMETERS

The output parameters also known as the response parameters are referring to the result after the experiment has been conducted. The output or response parameters in this experiment are surface roughness and material removal rate.

2.6.1 Surface Roughness

Surface roughness and integrity are of prime importance for machined automotive components in terms of aesthetics, tribological considerations, corrosion resistance, subsequent processing advantages, fatigue life improvement as well as precision fit of critical mating surfaces. Songmeneet al. (2102). Hence, the achievement of a predefined surface finish for automotive components directly translates to product quality. A wide variety of surface textures can be created from rough to mirror smooth. Surface Roughness is a measurable surface characteristic quantifying high frequency deviations from an ideal surface. Usually measured in micrometers (µm), it is a subjective property incorporating appearance, smoothness, etc. It is usually described by the arithmetic mean value (R_a) based on the mean of the normal deviations from a nominal surface over a specified “cutoff” length and is given in Equation(2.2).

$$Ra = \Sigma y \tag{2.2}$$

where, 'R_a' is the surface roughness, 'n' is the number of measurement points and 'y_i' is the surface deviation at measurement point 'i'

2.6.2 Material Removal Rate

Material removal rateis the quantity of material removed in forms of chip during the milling process by Matthew et al. (2012). When the material removal rate is higher, it becomes better due to faster processing or cutting and to save the power of cutting in accordance to Brian and Islam (2012). Coincidentally, although the higher value of material removal rate is good, it also causes the tool to wear easily and causes higher surface roughness; hence that is why the lower surface roughness and higher material removal rate must be selected carefully.

2.7 MACHINABILITY OF ALUMINUM ALLOY

Three of these materials are the common lightweight engineering materials include: aluminum, magnesium and titanium. Some of the most relevant material properties of these three materials are compared in Table 2.1 along with the properties of steel that is used in common industrial components as stated by Kouamet al. (2012).

On comparing the properties of these lightweight materials listed in table 2.1, it can be observed that aluminum having a density of a third of that of steel possesses twice its strength-to-weight ratio. Though the comparative properties of magnesium and titanium seem attractive, their alloys are plagued by severe machinability limitations. Table 2.2 shows the chemical composition of aluminum alloy 6061T6. Thus, aluminum with its numerous attractive physical and mechanical properties, especially its lightweight characteristic, is favored as the best candidate material for automotive component manufacturer.

Table 2.1: Relevant material properties of lightweight industrial metals.

	Steel	**Aluminum Alloy**	**Magnesium Alloy**	**Titanium(6Al4V)**
Density (kg/m3)	7850	2700	1810	4500
Yield Strength(MPa)	230	350	140	900
Tensile Strength (MPa)	430	400	200	970
Strength to Weight Ratio	0.05	0.15	0.11	0.22
Specific Cutting Energy (Ws/mm³)	2.7 - 9.3	0.4 -1.1	0.4-0.6	3.0 -4.1

Source : Kouam et al. (2012)

Table 2.2: Chemical composition of Aluminum alloy 6061T6

	Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Al**
Al 6061-T6	0.7	0.5	0.22	0.09	0.93	0.08	0.15	0.08	Balanced

Source : Kouam et al. (2012)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The performance of dry machining and minimum quantity lubrication procedure using coated carbide cutting tool was studied experimentally by evaluating the effect of cutting speed, feed rate, and depth of cut on surface finish of the aluminum alloy specimen. The flow diagram in Figure 3.1 illustrates the project procedure.

3.2 CUTTING TOOLS

The cutting tools that are involved in this experiment are of the coated carbide tools. The coated carbide tools can sustain a long tool life compared to other types of tools. The high level of material removal rate and long tool life are achieved through a balanced of wear resistance and toughness. By using more than one layer of various coating materials, it is in best interest to combine the advantages that each coating may present as stated by Ishan et al. (2012) Many insert grades have three layers of coatings to ensure good adherence between the insert substrate and coatings. The coated carbide use in this experiment is CTW-4615 follow by international standard organization (ISO) catalogue number. W 4615 is a coated carbide grade with TiAlN coating PVD with grade designation P35 M50. CT. Table 3.1 shows the composition of coated carbide inserts.

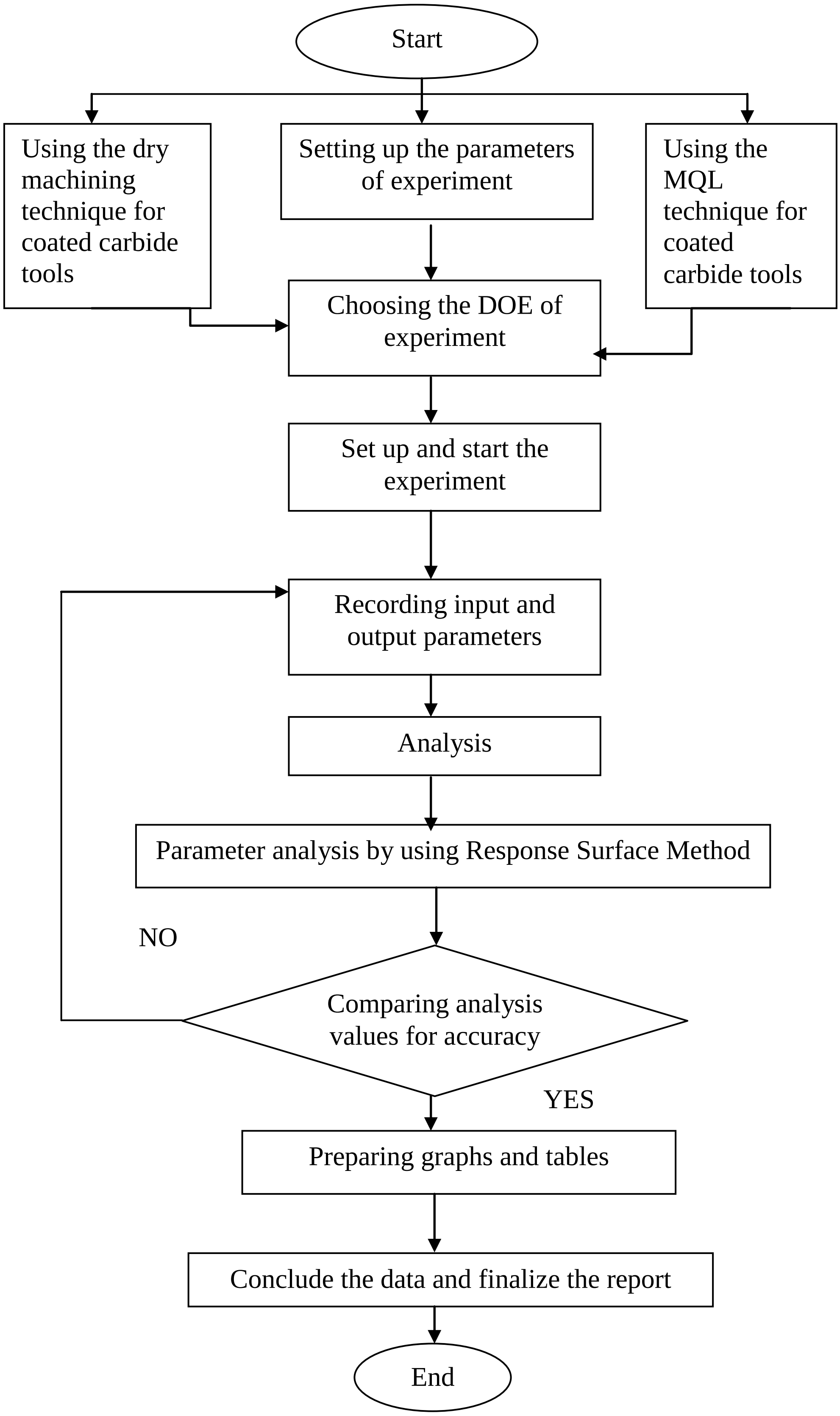

Figure 3.1: Flow chart of the study

Table 3.1: Composition of the coated carbide inserts

Type of carbide	Code name	Composition	Coating	Grain size
Coated carbide	CTW 4615	6 % of Co, 4 % carbide,90 % WC	PVD	4μm

(a)

(b)

Figure 3.2: (a) Cutting Tool Insert with Tool holder, (b) Coated Carbide Tool Insert

3.3 PROCESS PARAMETERS

The researchers had found that there are three main parameters that can affect a machining process and the output. The said parameters that needed to be considered during machining process are cutting speed, feed rate and the depth of cut so that the output can be produced as desired as written by Matthew et al. (2010). The type of machining, dry machining and minimum quantity lubricant is being done to find out what is the type of lubrication best suited to cut the aluminium alloy 6061-T6 and analyzing the effects that both types of machining made on the surface roughness of the work piece, tool life and material removal rate.