EVALUATION OF SURFACE ROUGHNESS AND POWER CONSUMPTION IN MACHINING FCD 450 USING COATED AND UNCOATED IRREGULAR MILLING TOOLS

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FITRIYANTI BINTI ARSYAD

Report submitted in partial fulfilment of the requirements
for the award of the degree of
B.Eng (Hons) Manufacturing Engineering

Faculty of Manufacturing Engineering
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JUNE 2015

EXAMINER'S APPROVAL DOCUMENT

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Manufacturing Engineering

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Name : FITRIYANTI BINTI ARSYAD

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Date :

SPECIAL DEDICATION

Dedicated to my beloved parents

ARSYAD BIN SULAIMAN
JAMI BINTIN SAPAWI

and

My Supervisor
ASSOCIATE PROF AHMAD RAZLAN BIN YUSOFF

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ABSTRACT

Machining is the most important manufacturing process in these modern industries especially for producing automotive component. Quality, productivity and cost saving in manufacturing industries is one of the main manufacturer focus in making mechanical product in Sapura Industry. In this project, the effects of different cutting conditions (spindle speed, feed rate, and depth of cut, machining length and machining time) on surface roughness and power consumption on FCD450 cast iron by using CNC milling machine are studied. The experimental output indicated average decrement 27.92% for surface roughness by using coated compare uncoated tool. Average decrement 9.32% for power consumption by using coated compare uncoated tool. The suggested cutting parameter for lowest surface roughness and lowest power consumption by using coated and uncoated tools are; cutting speed (3026 rev/min), feed rate (120 mm/min), depth of cut (0.75 mm), radial depth of cut (20 mm) ,machining time (73.5second) and machining length (300 mm). From the results, the optimum cutting speed (2587.95 rev/min), feed rate (280.28 mm/min), lowest depth of cut (0.75 mm), radial depth of cut (10.88 mm), machining time (72.5 second) and machining length (269.4 mm) is suggested for further analysis and experiment of coated solid carbide cutting tools to get optimum performance. From the results experiments, it can be concluded that using coated solid carbide give optimum results in the term of surface roughness, power consumption, tool wear and tool life as compared to uncoated tools in milling. High quality surface and high productivity is obtained using coated tool compare uncoated tools because using coated is more economical in terms of energy and power requirements which meet the high demand of the industry nowadays.

ABSTRAK

Pemesinan adalah proses pembuatan yang paling penting dalam industri moden terutama untuk menghasilkan komponen automotif. Kualiti, produktiviti dan penjimatan kos dalam industri pembuatan adalah salah satu tumpuan utama dalam membuat produk mekanikal untuk Industri Sapura. Dalam projek ini, kesan daripada keadaan pemotongan yang berbeza (kelajuan gelendong, kadar suapan dan kedalaman pemotongan, panjang pemesinan dan masa pemesinan) pada kekasaran permukaan dan penggunaan kuasa pada FCD450 besi tuang dengan menggunakan mesin pengilangan CNC telah dikaji. Pengurangan sebanyak 27,92 % terhadap kekasaran permukaan adalah dengan meggunakan alatan bersalut berbanding alatan yang tidak bersalut. Manakalah pengurangan penggunaan kuasa sebanyan 9.32% terhadap alatan bersalut. Parameter pemotongan yang dicadangkan untuk mendapatkan kekasaran permukaan dan penggunaan kuasa terrendah dengan menggunakan alatan bersalut dan alatan tidak bersalut adalah; kelajuan pemotongan (3026 put / min), kadar suapan (120 mm / min), kedalaman pemotongan (0.75 mm), dalam pemotongan (20 mm), masa pemesinan (73.5 saat) dan panjang pemesinan (300 mm). Daripada keputusan experimen untuk alatan bersalut, optimum kelajuan pemotongan yang dicadangkan untuk analisis lanjut dan eksperimen bersalut alat pemotong karbida pepejal untuk mendapatkan prestasi yang optimum adalah (2587,95 put / min) , kadar suapan (280.28 mm / min), pemotongan kedalaman paling rendah (0.75 mm), dalam pemotongan (10,88 mm), masa pemesinan (72.5 saat) dan pemesinan panjang (269.4 mm). Daripada keputusan eksperimen, dapat disimpulkan bahawa menggunakan alatan bersalut memberikan hasil yang optimum terhadap kekasaran permukaan, penggunaan kuasa, alat haus dan hayat alat lebih lama berbanding alatan yang tidak bersalut. Permukaan yang bagus dan produktiviti yang tinggi dapat diperolehi dengan menggunakan alatan bersalut berbanding meggunakan alatan tidak bersalut disamping ia lebih jimat dari segi tenaga dan kuasa bagi memenuhi keperluan dan permintaan yang tinggi daripada industri masa kini.

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LIST OF ABBREVIATIONS

CL	Chip Load
DOC	Depth of Cut
FR	Feed Rate
GPS	Geometry Product Specifications
ISO	International Organization for Standardization
ML	Machining Length
MT	Machining Time
RDOC	Radial Depth of Cut
SFM	Surface feet per minute
SS	Spindle Speed
T	Number of Teeth on the cutter

LIST OF SYMBOLS

(Fz)	Thrust force
Ra	Surface Roughness
VB	Flank Wear land
VB_k	Allowed Flank Wear land
Rz	Average Maximum Height
Rt	Maximum Height of Surface
Rv	Maximum Valley Depth
Rp	Maximum Peak Height
R Motif	Motif Parameter
C	Carbon
Si	Silicon
Mn	Manganese
P	Phosphorus
S	Sulphur
Mg	Magnesium
Fe	Iron

CHAPTER 1

INTRODUCTION AND GENERAL INFORMATION

1.1 PROJECT BACKGROUND

Machining can be defined as a process that involved removing the material from the work piece and cut it into desired size and shape in form of machining chip. It's also can be considered as the most essential process in manufacturing processes. Main industry goal's is to manufacture high quality product, as well as low cost in short time. One of the most important elements in machining is the tools and cost of each tool can be varied and expensive according to their function and endurance.

First step for machining in planning process is starting from selection of cutting tool to know the cutting condition as well as to obtain specific data of tool life, cutting force, surface roughness, chattering and vibration, which is traditionally carried out base on planner experiences and general knowledge which is need to measured and recorded to compare with standard part (regular cutting tool). Besides that, handbook and tool catalogues are used to know standard data of the tool and machine before run the task.

A new cutting tool performance behaviour test can be applied to help businesses gain a competitive edge and it's also describe all the tool characteristics'. The study of power consumed by the tool helps to find out the life of the tool for maximum productivity, helps to select the capacity of the motor required for the machine and it also helps for designing machine components. Wide of knowledge and have a better understanding about engineering material is essential for manufacturer during development.

To know characteristic of new cutting tool, various experiments should be conducted to obtain cutting tool specifies data to achieve the main general objectives which are to evaluate the power consumption and surface roughness effect of cutting tool due to variation of spindle speed, feed rate, depth of cut and radial depth of cut. To analyze surface roughness and power consumption of coated and uncoated irregular milling tool for optimum parameters in the machining length and machining time to measure the performance and to determine the optimum cutting parameters based on average surface roughness and power consumption result on the milling machine. Performance of machining process depends on the surface smoothness, and power consumption so that it's become the major topics in process planning and machining optimization in industry to increase the productivity of the product and lowering tooling cost.

1.2 PROBLEM STATEMENT

Quality and efficiency of the product in manufacturing industries is one of the main manufacturer focus and to increase the productivity of the product in Sapura Industry, one larger factor is selection of cutting tools and cutting condition for machining. To know characteristic of new cutting tool, various experiments should be conducted to get optimum cutting tool performance to achieve the main objectives tools to fulfil Sapura's requirement. This research project focused surface roughness and the power consumption test by FCD 450 cast iron using irregular milling tool coated and uncoated solid carbide. This material was been selected because they can be considered as materials that widely used in Sapura industry for block engine application.

1.3 OBJECTIVE OF THE RESEARCH

1. To evaluate the power consumption and surface roughness effect of cutting tool due to variation of spindle speed, feed rate, depth of cut and radial depth of cut.
2. To analyze surface roughness and power consumption of coated and uncoated irregular milling tool for optimum parameters in the machining length and machining time to measure the performance
3. To determine the optimum cutting parameters based on average surface roughness and power consumption result on the milling machine.

1.4 SCOPE OF STUDY

1) To conduct machining experiment of irregular end mill for coated and uncoated solid carbide end mill Ø20mm by using CNC KE55 Milling Machine.
2) To evaluate the surface roughness and power consumption effect of cutting tool due to variation of cutting conditions such as spindle speed, feed rate, axial and radial depth of cut, machining time and machining length.
3) To analyse and compare surface roughness and power consumption of coated irregular milling tool due to optimum parameter for cutting conditions.

1.5 FLOW CHART

The sequences of works have been planned for this project in order to achieve the project objectives. This flow chart is useful to ensure that all work regarding this project will be carried out as planned and smoothly. The process flow chart is shown in figure 1.1 below. Figure 1.1 shows the process starts by defining the project background and the objectives of the project. Research are done for journal and reading material regarding project, this step is very important to ensure that project run smoothly and to keep the project within its scope. Journal and reading material are review according to the project title and scope.

Procedure and methodology of the project are planned and recorded. In machining and experiment process the material of the project are determined, experiment method and fabrication of the tool are done and the calculation regarding economic value of the tool, if the result and analysis are acceptable and within the project objectives, the data from the machining and experiment are discussed and then concluded. Figure 1.1 show the project flow chart. Whereas Gantt chart can be referred in appendices A.

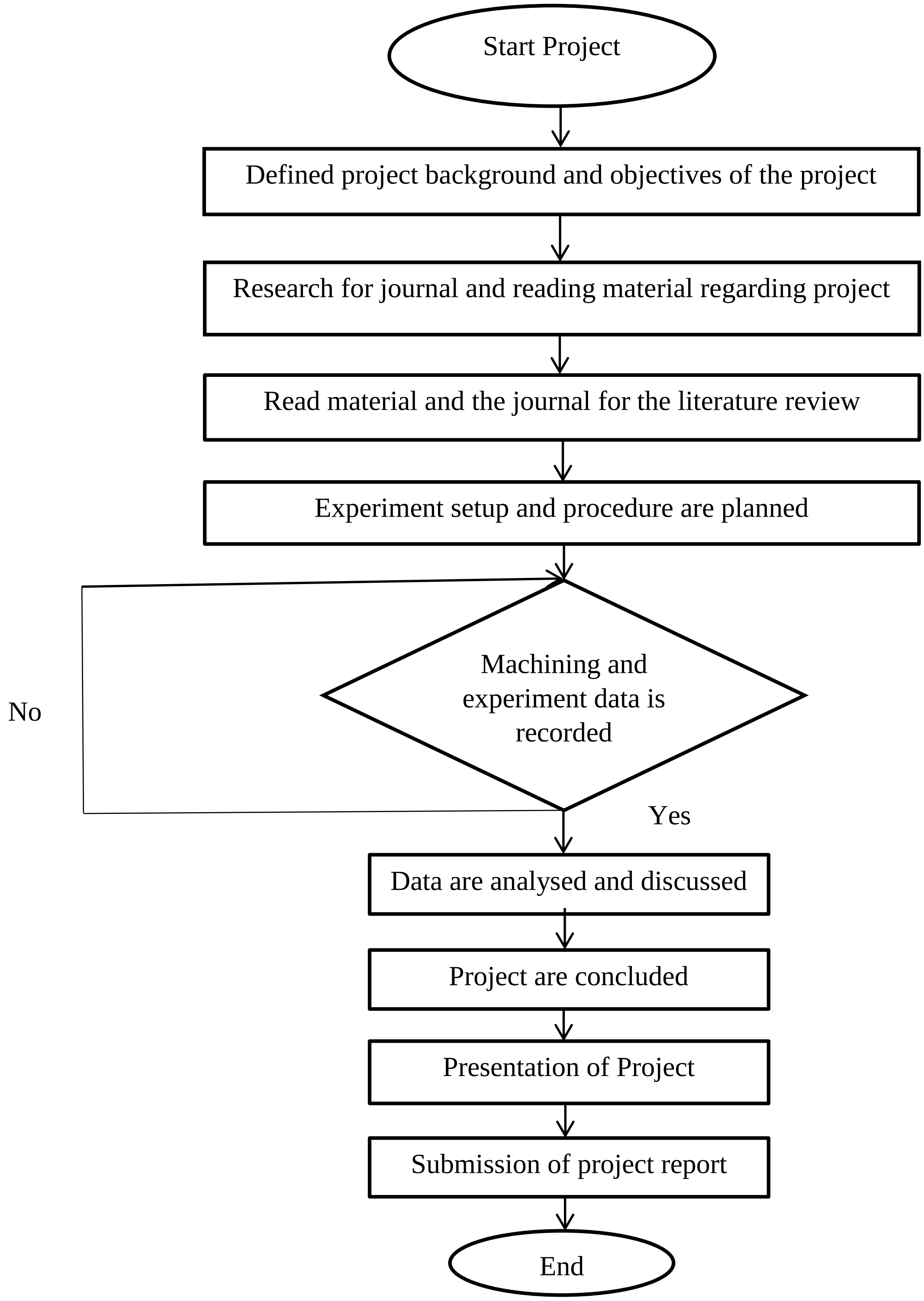


Figure 1.1: Project flow chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

General objective for the new cutting experiment done by previous researcher is to know their performance behaviour such as tool wear, tool life, vibration, surface roughness, power consumption on the machine and etc. according their standard test. (Kusuma.N, 2014). But one of the objective for this experiment is to understand the behaviour of tool for coated and uncoated solid carbide, workpiece surface roughness and power consumption by using CNC Milling Machine. The good surface roughness is depend on the characteristic of tool used because the tool life is one of the most importance aspect must be considered because tool condition monitoring is vital to prevent workpiece and the tool from damage as well as to increase the effective machine time of machine tool. Tool wear is a phenomena where the material used to construct the cutting tool gradually peeling off during machining process due to the combination of mechanical-thermal-chemical process (Cook, 1973).

Literature review was conducted to achieve the objective of this experiment by set up the coated and uncoated 8 flute solid carbide as the cutting tool, FCD450 cast iron block as the workpiece material in order to acquire the result on surface roughness and power consumption on the work piece by using CNC milling machine. Productivity at the machine and machine efficiency can be improved by using coated and uncoated 8 flute solid carbide cutting tool with their optimum parameter. To realise it, some of the suitable test must be implement follow standard test about surface roughness and power consumption testing and all related data is recorded for future analysis.

2.2 MACHINING

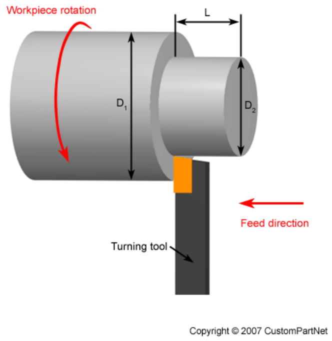
Definition of the machining can be described as the process where the cutting tool remove unwanted material from the work piece by follow machining standard parameter to produce the desire shape. There have three major type of material removal process which are mechanical, chemical and thermal. Metal cutting is one of the most significant manufacturing processes in the area of material removal (Chen J.C, 1997). (Black J.T, 1979) defined metal cutting as the removal of metal chips from a workpiece in order to obtain a finished product with desired attributes of size, shape, and surface roughness.

The common used in cutting tool experiment for material removal process is only mechanical. Machinability can be expressed as the easiness or difficulty in a machining operation involving cutting conditions such as cutting speed, feed rate and depth of cut. The machinability of a material can be defined by measuring the tool life, surface roughness and cutting force.

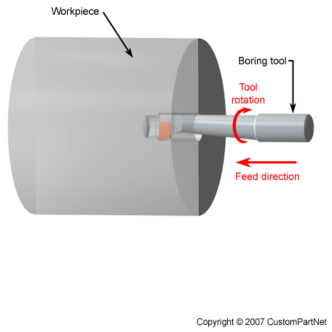
2.2.1 Turning

Turning is one of the widely used machining processes. The productivity of the turning process is mainly limited by machine tool chatter caused by the interaction between cutting tool and workpiece structure and dynamics of the cutting process. Study of force is very importance in turning operation because cutting force relate strongly with cutting performance such as surface accuracy, tool wear, tool breakage, cutting temperature, self- excited, forces vibration and etc., (Silliman, 1992). Coated and uncoated carbide tools are widely used in the metal- working industry and provide the best alternative for most turning operations (Deepak, 2013).

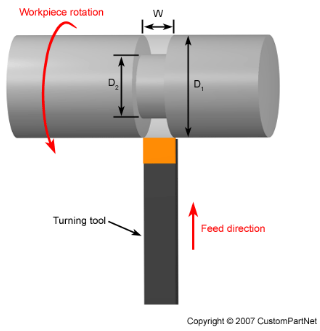
Figure 2.1 shows type turning operation such as turning, boring, facing, grooving and thread cutting allow for a wide variety of features be machine, including slot, taper, thread, flat surface, and complex contour.



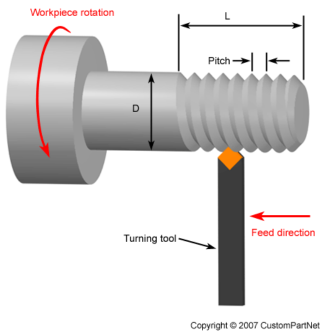
a) Turning Operation



b) Boring Operation



c) Grooving Operation



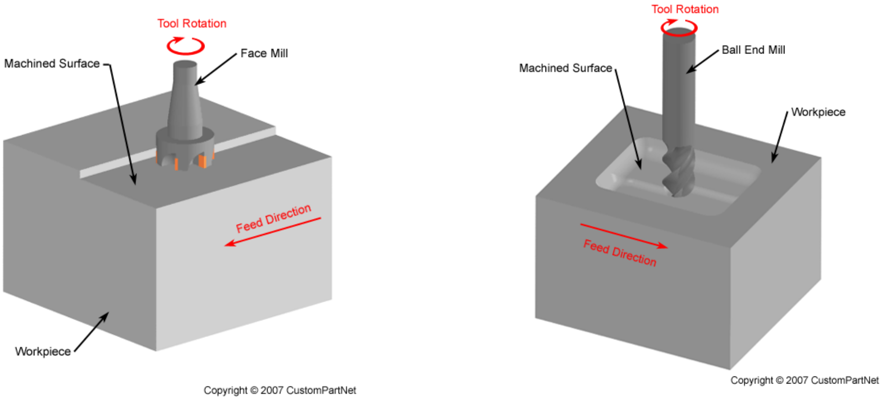
d) Thread Cutting Operation

Figure 2.1: Type of turning operations

Sources: http://www.custompartnet.com/wu/turning

2.2.2 Milling

Milling is one of the multi-point cutting for material removal processes which using sharp cutting tool to remove the material against the workpieces. Milling is a fundamental process and the most encounter metal removal operation in manufacturing industry. The quality of a milled surface is a key role for improving fatigue strength, corrosion resistance, and creep life (Mohammed T, 2007). The process of generating a milled surface is affected by several factors, some of them, namely the cutting conditions and tool geometry, are of primary importance in determining the quality of a milled surface (Evalio et. al., 1983). (Jalili Saffar et. al., 2009) stated that the main parameters in machining affecting tool deflection and surface finish are axial depth of cut, radial depth of cut and feed rate. (Nagi et. al., 2008) described that surface roughness is more sensitive to the feed rate and the depth of cut. Figure 2.2 shows type of milling operations.



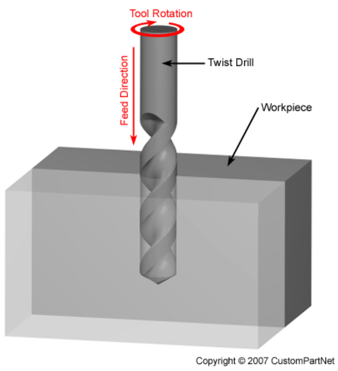
a) Face Milling **b)** End Milling

Figure 2.2: Type of milling operations

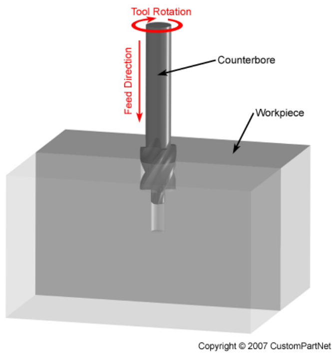
Sources: http://www.custompartnet.com/wu/milling

2.2.3 Drilling

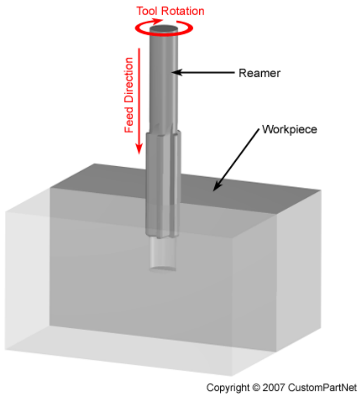
Drilling process is one of the most importance machining process that have been usually used in industry for manufacturing districts (Bagci, 2006). Drilling is the process of rotating cutting tool to remove material from the stationary solid material workpiece to create a hole or enlarge holes, high precision holes and threated holes by used drill bit. For broaching and sawing, it’s not required rotation of the tool for multi-point cutting process. Counterboring, countersinking and tapping are the example of drilling process. About 75% of the drilling operation is used in manufacturing area for metal cutting process (kovacs, et. al., 2011). Figure 2.3 shows 4 type of drilling operation.



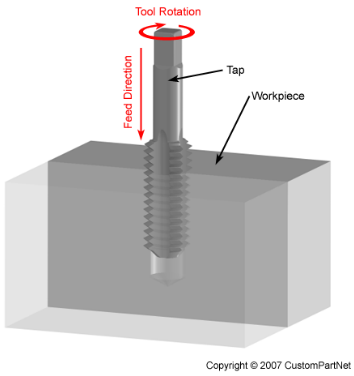
a) Drilling operation



b) Counterboring



c) Reaming operation



d) Tapping operation

Figure 2.3: Type of drilling operation

Sources: http://www.custompartnet.com/wu/milling

2.2.4 Abrasive machining

Abrasive machining is the operation using any tool that have small abrasive particle to remove a small chip of material on the workpiece same as milling or turning process. Main purpose for this process is to get the high quality of surface finish and increase the quality of the product (zero defect). The most common abrasive using is grinding as shown in Figure 2.4.

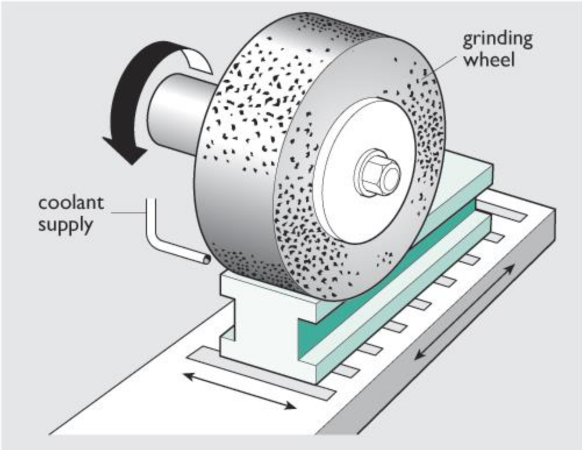


Figure 2.4: Grinding process

Sources: Grinding Process, 2010

2.3 CNC MILLING MACHINE

Milling machine is one of the most multifunction machine tools. In 1820, Eli Whitney is the first person that invent and built the milling machine. One of the first studies to examine energy usage of computer numerical controlled (CNC) machines was done by (Filippi et. al., 1981). This study found that the largest loss of efficiency in machining was due to machine under- utilization Figure 2.5 show example of cutting operation that can be done my milling machine. End, milling is wide used in industry and one of the importance machining operation because it has capability to obtain various profile and curve surface (Kalpakjian and Schmid, 2006).

Computer Numerical Control (CNC) machines are widely used in manufacturing industry. The industries that commonly used this machine are including automobile and aerospace industry (Mike et. al., 1999). Benefit using CNC milling machine is this machine give 100% correct with what they produce when being programmed correctly. Besides that, CNC machine more expensive compare to conventional machine and high skill worker are required to operate CNC machine.

Figure 2.5: CNC Milling Machine

Sources: http://www.tennesseequipment.com/East-Cost-/South-Carolina/Manufacturers-/New-milltronics-cnc-vertical-milling-machine-MM18.pl

2.4 END MILLING PROCESS

End milling is the operation that the tool moved across the stationary workpieces to get rid of the material from the surface of the work material by rotating tool on an axis perpendicular (Kalpakjian and Schmid, 2006). It's also very importance process because of its capability to produce various profile and curve surface. End milling is the widely used operation for metal removal in a variety of manufacturing industries including the automobile and aerospace sector where quality is an important factor in the production of slots, pockets and moulds/dies (Mike et. al, 1999; John and Joseph, 2001). Therefore, the desired finish surface is usually specified and the appropriate processes are selected to reach the required quality. Several factors influence the final surface roughness in end milling operation.

Factors such as spindle speed, feed rate, and depth of cut that control the cutting operation can be setup in advance. However, factors such as tool geometry, tool wear, and chip formation, or the material properties of both tool and workpiece are uncontrolled. (Huynh et. al., 1992). (Abbas Fadhel Ibraheem et. al., 2008) investigated the effect of cutting speed, feed, axial and radial depth of cut on cutting force in machining of modified AISI P20 tool steel in end milling process.

2.5 MACHINE PARAMETER

The selecting and implementing optimal machining condition is one of the importance need in machining operations. This is because it can affect the quality of product, productivity, total manufacturing cost per component and other suitable criterion. (Jaharah A.G, 2009) has researched, spindle speed, feed rate and depth of cut, radial depth of cut are chosen to be the independent variables. All this variable cutting parameter are chosen because these variable are controllable machining parameter and they can be used to predict surface roughness which will the enhance product quality, reduce tool wear and reduce tooling cost. (Reddy et. al., 2011) to achieve the minimum surface roughness, the appropriate process parameters are determined. Nose radius, cutting speed, feed rate, axial depth of cut and radial depth of cut are considered as process parameters.(Oktem et. al., 2005) used the mathematical model for Ra in terms of cutting parameters (feed, cutting speed, axial depth of cut, radial depth of cut and machining tolerance).

The spindle speed is the rotational frequency of the spindle of the machine, measured in revolutions per minute (RPM). Tool wear, breakage and tool chatter is caused by excessive spindle speed that can lead potentially dangerous conditions. To overcome this problems, choosing correct spindle speed depend on the material and tools one of the most influence factor must be considered to obtain better quality of surface finish and enhance tool life. (Mohammed et. al., 2007) stated that the most important interactions, that effect surface roughness of machined surfaces, were between the cutting feed and depth of cut, and between cutting feed and spindle speed.

The speed on the surface of workpieces across to the cutting tool for milling process is known as cutting speed because there have speed difference between its which is relative velocity or it can be expressed as rate of distance long the workpieces surface. (Kalpakjian and Schmid, 2006). Before start the experiment, it is necessary to identify the factor effect the calculation of the spindle speed which are material of the cutter and the work material. Besides that, the tool life of cutting tool must be considered to avoid machine break down. Cutting speed is measured in surface feet per minute (SFM).

Feed was found to be the most influencing cutting parameter as far as surface finish of the machined surface is concern. (Sonawane Gaurav et. al., 2011) has reported the High speed used with low feed gives good surface finish, but higher feed values are proved to be unfavorable for both tool wear as well as surface finish. For milling, it often expresses in units of distance per time. Feed rate dependent on many factors including type of tool, high speed carbide of carbide, and coated and uncoated. Other factors are desire surface finish and strength of workpiece. Furthermore, feed rate depend on the power available at the spindle and rigidity of the machine and tooling setup.

$$\mathbf{FR = RPM \times T \times CL} \tag{1}$$

- *FR* = the calculated feed rate in inches per minute or mm per minute.
- *RPM* = Speed for the cutter.
- *T* = Number of teeth on the cutter.
- *CL* = the chip load or feed per tooth. This is the size of chip that each tooth of the cutter takes.

Material removal rate can be define as the depth of cut. Depth of cut also considered as one of the major of independence variables in the cutting process especially for end mill process. Depth of cut must be limited to value that will no distort the workpiece caused it to slip or overload the machine .Increasing the cutting speed and depth of cut on workpiece will caused temperature of cutting zone also increasing. (Yang and Liu, 1999). Excessive depth of cut value may break the cutting tool. (Jalili Saffar R. et. al., 2009) stated that the main parameters in machining affecting tool deflection and surface finish are axial depth of cut, radial depth of cut and feed rate. (Nagi et. al, 2008) described that surface roughness is more sensitive to the feed rate and the depth of cut.

Radial depth of cut is the depth of the tool along its radius in the work material. (Kalpakjian and Schmid, 2006). When radial depth of cut is less than the tool radius and equal the tool diameter and it's creating a slot cut type and it will produced peripheral cut. Whereas the large depth of cut will need a low feed rate and its will reduce the tool life. (Reddy et. al., 2011) found that to achieve the minimum surface roughness, the appropriate process parameters are determined. Nose radius, cutting speed, feed rate, axial depth of cut and radial depth of cut are considered as process parameters. The Figure 2.6 shows the type of depth of cut.

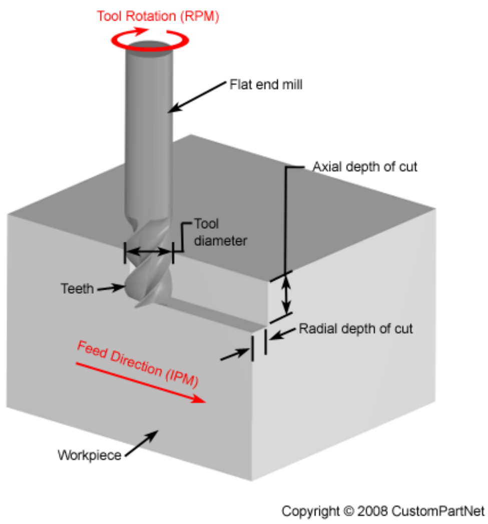


Figure 2.6: Type of depth of cut

Sources: http://www.custompartnet.com/wu/milling

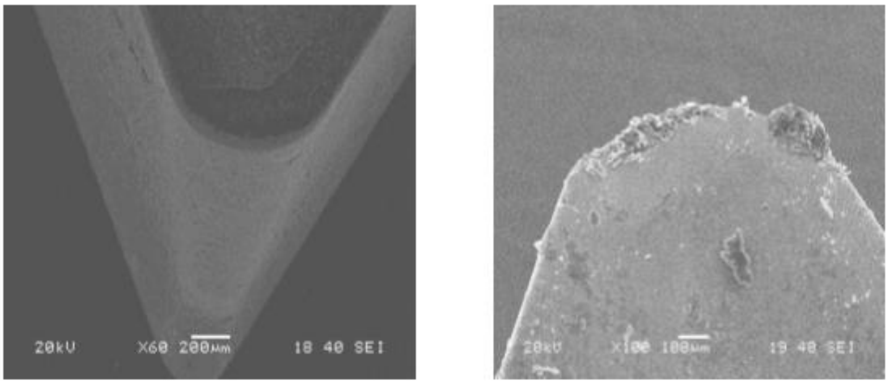
Cutting force is just one or the parameter to be considered for this experiment. According to (Kim et. al., 1979), difficulty machine on the workpieces is define as the cutting force. To achieve high quality of the product surface, a small cutting force is desire to avoid spindle axis product high vibration. Besides that, the cutting force are more sensitive to the vibration of the feed. According to (Khettabi et. al., 2010) the thrust force (Fz) increase as the feed rate increases for the cast wrought material. Cutting speed, feed, and depth of cut are 3 importance parameter are suitable used for a new cutting performance behaviour tests.

2.6 MACHINE ABILITY

2.6.1 Tool wear

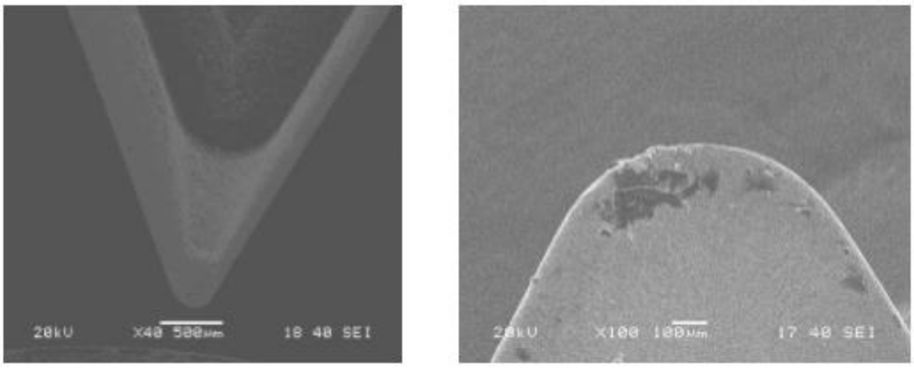
Tool wear is a phenomena where the material used to construct the cutting tool gradually peeling off during machining process due to the combination of mechanical-thermal-chemical process (Cook, 1973). The ISO 8688:1989 standard also define the tool wear as the changing shape of the tool and caused tool deformation during cutting process when the tool no longer perform their function. Wear rate is defined as the volume or mass material removed per unit time or per unit sliding distance and is a complex function of time (Bhushan, 1999). (Sharif and Rahim, 2007) found that the flank wear land increases gradually at low cutting speed. At low cutting speed wear mechanism is due to abrasion (Arsecularatne, 2006).

Finding form (Sharif and Rahim, 2007) also show that feed rate and depth of cut play an important role in determining the tool life. (Jaharah et. al., 2007), found that combination of high feed rate and depth of cut would cause cracking and fracturing of the cutting edge, and led to catastrophic failure of the tool edge. Figure 2.7 and 2.8 shows image of the wear of uncoated tools and coated tools before and after machining.



(Before machining) (After machining)

Figure 2.7: Image showing the wear of uncoated tools



(Before machining) (After machining)

Figure 2.8: Image showing the wear of coated tools

Sources: Valery Marinov, (2010)

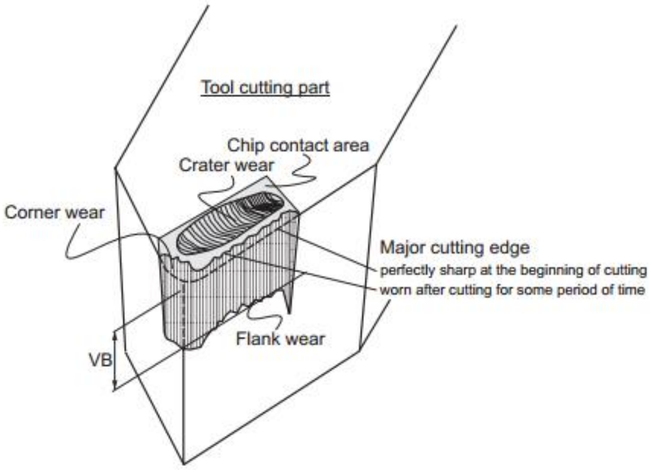


Figure 2.9: Type of wear observed in cutting tools

Sources: Valery Marinov, (2010)

Crater wear can caused tool breakage and weaken the tool wedge. It also form a concave section on the tool face because of chip sliding on the surface. Flank wear is caused the friction between machined surfaces of the tool flank on the workpiece. It is also can be increasing cutting force and as well as cause tool failure. It is also known as wear land. Corner wear is occurs on the tool corner and it's also part of the flank wear.

Cornet wear can caused shortens the cutting tool and also error in machining because of inaccurate dimension of the cutting tool, which can reach value about 0.03-0.05 mm.

2.6.2 Tool Life

The life of a cutting tool is based on the amount of wear that has occurred on the tool profile. (Ishan B Shah et. al., 2012) stated in order to establish an adequate functional relationship between the tool life and the cutting parameters (cutting speed, feed, and depth of cut), a large number of tests are needed, requiring a separate set of tests for each and every combination of cutting tool and workpiece material. (Jaharah A.G, 2009) found that the effect of rate and depth of cut are 30% and 70% respectively on the tool life. The most common wear occur in machining process is flank wear, therefore the parameter that must be control are width of flank wear land, VB. 0.4mm is the safe limit or know as allowed wear land which is represent by VBk for solid carbide cutting tool as shown in the Figure 2.9.

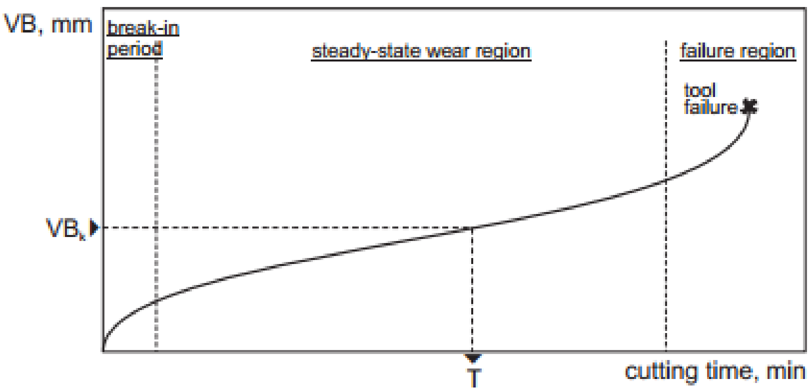


Figure 2.10: Relationship between save limit of the cutting tool and cutting time (min)

Sources: Valery Marinov, (2010)

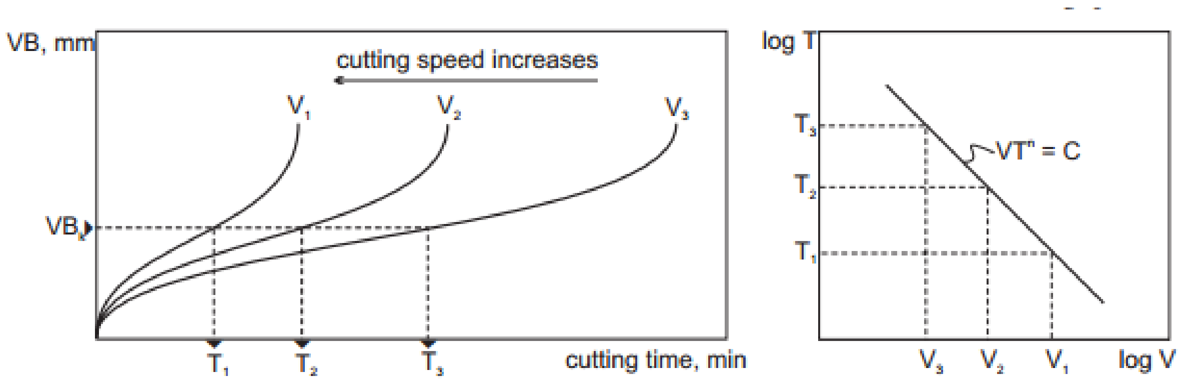


Figure 2.11: Relationship between flank wear and cutting time (Left) & relationship between Log T and Log V (Right)

Sources: Valery Marinov, (2010)

2.6.3 Surface Roughness

The most quality measures in mechanical product is depend on the surface roughness and tolerance .The quality of surface is one of importance criteria that need to be get after perform milling operation. This is because good quality milled surface significant improves fatigue strength, corrosion resistance or creep life. (Mohammed T et. al., 2007)

(Dr Mike S lou et. al., 1999) cited that the term surface roughness and surface finish are widely used in industry and are generally used to qualify the smoothness of surface finish. Formerly manufacturing engineer used Ra (surface roughness) to know about the surface finish during milling process. In accordance ISO 468(1982). Ra is one of the parameter that define an arithmetic mean value of machined surface profile.

(Gokkaya H. et. al., 2005) described that surface roughness is affected by the cutting tool coating material, cutting speed and feed rate. The surface roughness can be measured by using a surface roughness tester and Figure 2.12 shows how the profile meter work on the wprkpiece surface. (Babur Ozcelik, 2006) describe that variables, R_a is also affected by tool life indicators such as tool wear and tool edge fracture.

A good combination of cutting speed and feed rate can provide better surface qualities (Gokkaya, H. et. al, 2005). Besides that, there have many factor that can causes poor surface finish in milling operation. One of the factor are vibration on the machine, chip formation and geometrical contributions. (Sidda Reddy. Bet. al., 2011) found to achieve the minimum surface roughness, the appropriate process parameters are determined. Nose radius, cutting speed, feed rate, axial depth of cut and radial depth of cut are considered as process parameters.

Examples of the most popular standards used by DMI to measure surface roughness is ISO 4288 1997, Geometrical Product Specifications (GPS) - Surface Texture: Profile Method- Rules and Procedures for the assessment of surface texture. Here are dozens of different surface finish parameters that can be reported, some of the more common ones are:

Ra – Roughness Average
Rz – Average Maximum Height
Rt – Maximum Height of the Surface
Rv – Maximum Valley Depth
Rp – Maximum Peak Height
R Motif – Motif Parameter

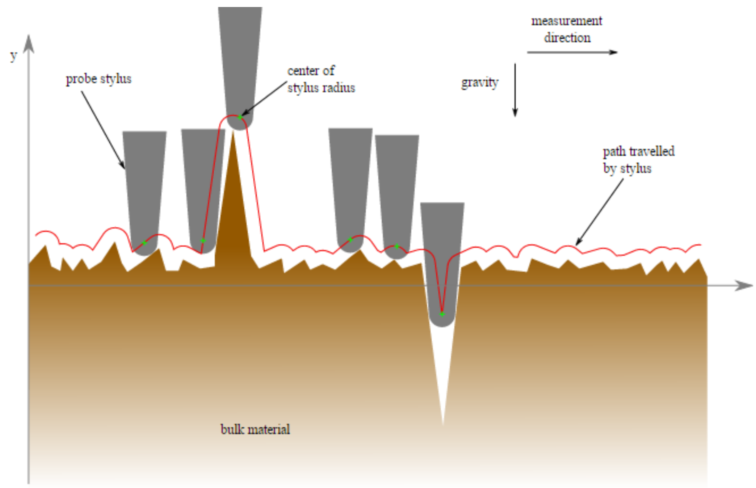


Figure 2.12: How a profile meter work on the workpiece surface

Sources: https://en.wikipedia.org/wiki/Surface_finish.

2.7 POWER CONSUMPTION

Energy savings is one of the most important features in consumer products and industrial equipment. This same trend applies in the machine tool industry. A survey of recent literature shows that many research efforts have been made towards this target in the machine tool industry. (Diaz et. al., 2010) investigated the reuse of energy regenerated from the spindle motor. Power consumption of machine tool behaviour has been presented by Kordonowy (Kordonowy D, 2002). There are two sections of power consumption in machine tools.

(Guoyong Zhao et. al., 2014) found that the research on energy consumption in machining is helpful to analyse the machine tool energy characteristics, optimize process parameters and machine tool components for energy saving. Specific energy consumption expresses the required energy consumption when cutting unit volume material. (Zahari taha et. al.,) found that machining time is the most influencing factor in power consumption. The power consumption of each of these varies mainly with operation time. Reduction of electrical energy for machining and peripheral devices plus shortening of the cycle time are the keys to reduce power consumption. Electrical energy can be reduces by shutting down unnecessary device during set-up and minimizing wait time. (Mori M. et. al., 2011).

2.8 CUTTING TOOLS AND WORKPIECE

2.8.1 Cutting tools

Cutting tool is a cutter or any tool equipment that used to eliminate material from the workpiece to form desire shape and size. Cutting tool must be made from material harden than material of workpiece which is to be cut (workpiece). (Jaharah A.G, 2009) stated that carbide tool is important in machining application due to availability and cheap as compared to other cutting tool material, even though it is preferred in machining cast iron. Three importance characteristics of cutting tool in milling process. First, the material hardness of cutting tool is hard and strength of the cutting tool is high at high temperature because heat is generated during metal cutting process. Second the cutting tool toughness to avoid tool from fracture. Third, the cutting tool must have specific data about tool wear resistance and too life.

Solid carbide tool are selected for this experiment because solid carbide is the common material used in industry, high resistance to abrasion and also have hardness up to about HRC90. Solid carbide is suggested for milling process that has a unique properties of such as thermal expansion, compression and tensile stress, brittles and wear resistance. (Sonawane Gaurav et. al., 2011) describe that, coating have unique properties, such as lower friction, higher adhesion, higher resistance to wear and cracking, acting as diffusion barrier and higher hot hardness and impact resistance. (Liew et. al., 2008) found that while machining AISI 420SS coated tools exhibit higher wear resistance that uncoated one, highest flank wear was found at the flank face near the DOC zone. This improvement had a major impact on the economics of machining operation in conjunction with continued improvement in the design and construction of modern machine tools and their computer controls.

(Sonawane Gaurav et. al., 2011) found that coated tools show better surface finish than uncoated tools. This is due to the reason that when uncoated tools are used for machining, the work material adhere on to the machined surface because of more tool wear. Coated and uncoated 8 flute solid carbide D20 mm as shown in Figure 2.13 were chosen to compare their characteristics between coated and uncoated behaviour. In this experiment used Titanium Aluminium Nitride (TiAN), violet bronze in colour, actually forms a hard aluminium oxide layer in hot (> 800ºC) as coated solid carbide tool.

a) coated end mill

b) uncoated end mill

Figure 2.13: uncoated and coated 8 flute End Mill solid carbide

2.8.2 Workpiece Material

The workpiece that was used in this experiment is cast iron as shown in Figure 2.14. According to ISO requirement the length per diameter ratio of the workpiece material supposed less than one in milling process experiment. Workpiece must be soft compare the material of cutting tool. The ductile cast iron has good mechanical properties, and is widely used for parts of automobiles, construction machinery, machine structure and so on (Morrogh.H, 1948). Cast iron is comparatively brittle material; therefore it is not suitable for product where a sharp edge or flexibility is required. It also has a property which is strong under compression but not under tension (Gonzalez & Bhadeshia, 2001).

(Jaharah A.G, 2009) studied the machinability of 500 FCD ductile cast iron using coated and uncoated carbide tool in dry machining condition. Casting of grey cast iron has relatively few shrinkage cavities and little porosity (Kalpakjian & Schmid, 2001). Generally, white cast iron is hard and brittle, which is difficult to machined (Gonzalez & Bhadeshia, 2001). In addition, the casting process is never perfect especially when dealing with large components (Gonzalez & Bhadeshia, 2001). FCD 450 is widely used in automotive industry such as for fuel pump and oil pump, engine cylinder and cranks shaft. This material has a great potential due to good mechanical property, easy to cast and cheap.

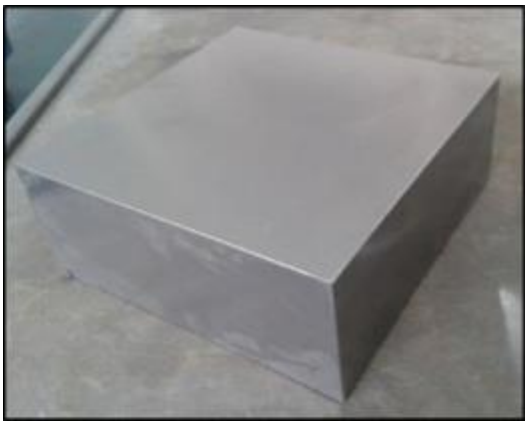


Figure 2.14: FCD450 Cast Iron

2.9 SUMMARY

After all the discussion done by various researchers it was conclude that end milling is the widely used operation for metal removal in a variety of manufacturing industries including the automobile and aerospace sector where quality is an important factor in the production of slots, pockets and moulds/dies (Mike et al, 1999; John and Joseph, 2001). (Sonawane Gaurav et. al., 2011) has studied the comparative performance of coated and uncoated carbide insert in dry end milling of stainless steel (SS 316L). (Jaharah A.G, 2009) studied the machinability of 500 FCD ductile cast iron using coated and uncoated carbide tool in dry machining condition. (Morrogh.H, 1948) use the ductile cast iron because it has good mechanical properties, and is widely used for parts of automobiles, construction machinery, machine structure and so on.

(Dr Mike S Lou et. al. 1999) in his journal cited that the term surface roughness and surface finish are widely used in industry and are generally used to qualify the smoothness of surface finish. (Mohammed et. al., 2007) have studied the most important interactions, effect surface roughness of machined surfaces, were between the cutting feed and depth of cut, and between cuttings feed and spindle speed. (Ishan B Shah et. at., 2012) stated in order to establish an adequate functional relationship between the tool life and the cutting parameters (cutting speed, feed, and depth of cut), a large number of tests are needed, requiring a separate set of tests for each and every combination of cutting tool and workpiece material.

(Sonawane Gaurav et. al., 2011) has studied the effect of machining length and machining time to the surface roughness and average flank wear. (Guoyong Zhao et. al., 2014) found that the research on energy consumption in machining is helpful to analyze the machine tool energy characteristics, optimize process parameters and machine tool components for energy saving. (Andy and Jonathan , 2013) done experiment that to develop an understanding of the relationship between peak power and energy consumption with machining parameters, spindle and total machine tool power are measured directly during a series of dry and wet end milling tests on a 3-axis CNC milling machine.

From the previous researcher (Sonawane Gaurav et. al., 2011) found that coated tools show better surface finish than uncoated tools. This is due to the reason that when uncoated tools are used for machining, the work material adhere on to the machined surface because of more tool wear. Generally, at the combination of low cutting speed, feed rate and depth of cut resulted in better tool life. (Ghani et. al., 2004) obtained similar results when machining hardened steels. However, increase of cutting speed while keeping the feed rate at high value would further shorten the tool life.

The main objective of this paper is to investigate the effect of spindle speed, feed rate, axial depth of cut, radial depth of cut, machining length and machining time on the surface finish and power consumption of the machine surface of FCD450 by using coated and uncoated irregular milling tools.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, all the method and process that used is based on the earlier research will compromised. Methodology is the precise way of accomplishment an operation that implies precise deliberative at the end of each stage. The purpose of this methodology is to make sure the process of this research is follow from beginning until the end of the project. Figure 1 shows an illustration of simple flow chart indicate the process flow.

For this experiment, procedure and condition for tool life has been designed for coated and uncoated end milling and FCD 450 cast iron workpiece .The flow chart is very importance to investigate in order to achieve the objective. Provide a flow chart before starting the research for the experiment. The experiment work of this research are based on flow chart. For the first step, select the parameter that will be used and list all control variable and measure variable that will be involved. In this experiment, tool wear rate and surface roughness are depend variable while spindle speed, feed rate and depth of cut are independence variable. Next step is preparing parametric study.

The next stage after compiling experiment is to provide raw material and tools that will be used in experiment. The specimen will be cutting by using bend saw machine and the dimensional are 150 mm x 150 mm x 50 mm. After that, the experiment is run to get the measurement of surface roughness and tool wear. Data is collected and continue with result plotted using originPro8 software. OriginPro8 software is used to find the importance factor that contribute to result beside to find optimum machining parameter.

The last step is write the conclusion from overall research and the data is documented in a form of report.

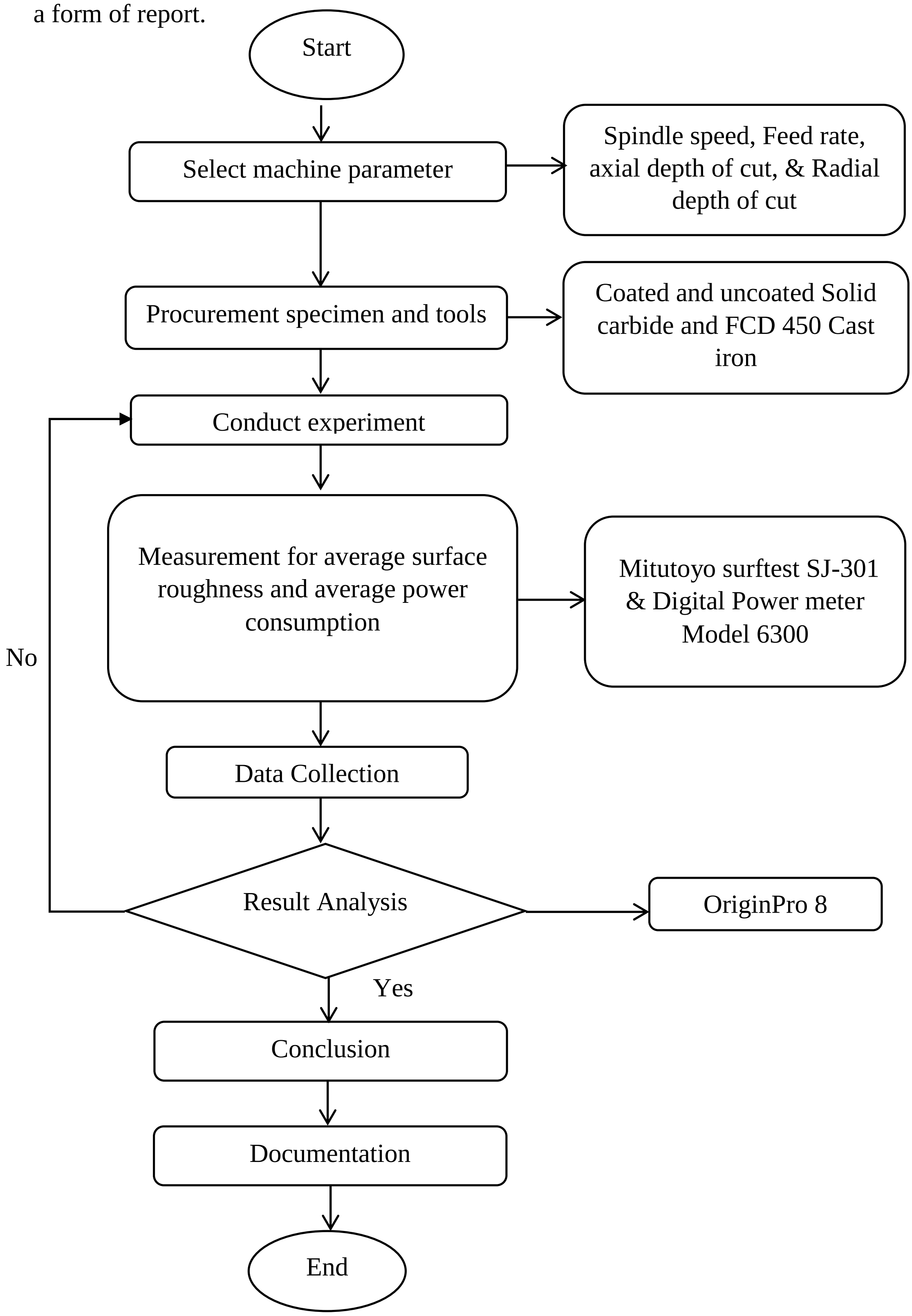


Figure 3.1: Methodology flow chart

3.2 RAW MATERIAL

The material selected for this research is FCD 450. The ductile cast iron has good mechanical properties, and is widely used for parts of automobiles, construction machinery, and machine structure and so on. The dimension for this raw material is 150 mm x150 mmx50 mm as shown in the Table 3.1. Figure 3.2 shows the process flow occurred on the workpiece for the tool life and surface roughness test.

Table 3.1: Chemical composition of the ductile cast iron (mass %)

Sources: Hara T, (2013)

	C	Si	Mn	P	S	Mg	Fe
FCD450	3.43	2.37	0.40	0.02	0.01	0.17	bal

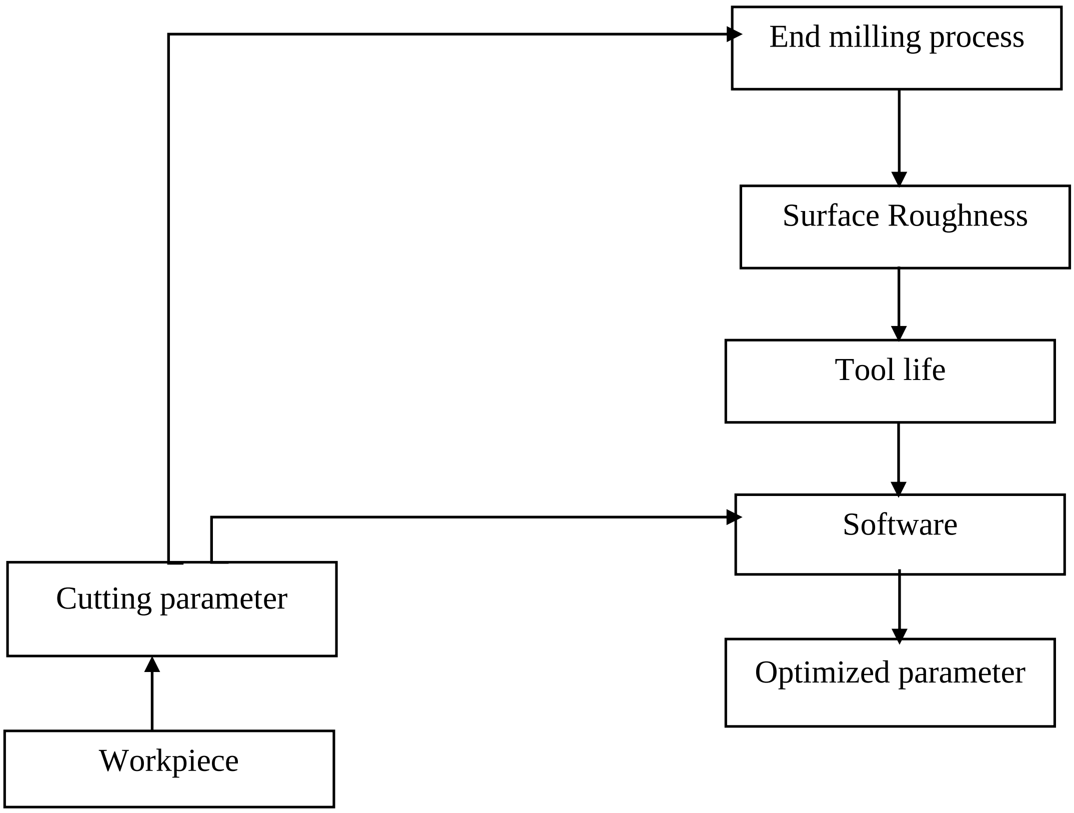


Figure3.2: Workpiece flow chart

3.3 TOOL

The selection of cutting tool is the most importance factors in machining operations for this research. 8 flute coated and uncoated solid carbide end mill is selected as the main cutting tool. Solid carbide are thermal stable and high resistance to abrasive wear. Rigid setup and accurate spindle are necessary for peak performance. The coated and uncoated solid carbide used is about diameter 20mm.

3.4 MACHINE

In this experiment, 3-axis Makino KE55 CNC milling machine shown in figure 3.3 is used for get data of tool wear and surface roughness of the cutting tool. This machine can be used to mill material and also conduct for drilling process. CNC machine have 3 axis that can be move difference axis which are X, Y and Z direction.

The most condition of milling machine shall have sufficient power and physical capacity, and the design should be stable to avoid high vibration or deflection during the test. Cutting condition which cause chatter should be not used. According to ISO standard, the feed speed under load shall be constant and transverse required for test should be not exceed 0.75 times limit of motion of the axis. Whereas all the data such as spindle speed axis orientation, vertical should be recorded. The most importance parameter to achieve this objective of the experiment are feed rate, spindle speed, depth of cut can be key in in the G-code programming.

According to ISO standard, before any testing is commenced, the machine tool should be warmed up by running the spindle for a minimum period of 30 min at a speed of 0.7 times the maximum available spindle speed or at the speed to be used in the test. At five minute interval during the period of the feed motion should be engaged to cause an axis movement at lease to tat required for the test, in the region to be for testing and the axis then returned at rapid transverse. Table 3.2 shows the detail Makino Ke555 Basic Specification that useful for milling experiment capability.

Figure 3.3: 3-axis Makino KE55 CNC milling machine

Table 3.2: Makino Ke55 Basic Specifications

Machine type	**Vertical**
Control	CNC
Number of Axes	3
X axis Travel	550mm
Y axis Travel	320mm
Z axis Travel	350mm
Spindles	1
Motor Power	5.6kW
Maximum spindle speed	4000RPM
Maximum Cutting Feed	5000mm/min
Maximum Load	200kg

3.5 EXPERIMENTAL SETUP

3.5.1 Experimental Design and Milling Parameter

The cutting condition was carried out on a vertical milling machine. Surface roughness of the carbide was measured using surface roughness tester. Table 3.3 show the cutting condition that used in the milling experiment.

Table 3.3: Equipment of experiments

Work-piece	Material FCD 450 cast iron Size : 150 x 150 x 50 mm^3
End Mill	Material 1 : Coated solid carbide Material 2 : Uncoated solid carbide Flute: 8 Diameter : 20mm Length : 80mm
ISO Standard Setting	ISO1997
Cutting conditions	I, II, III, IV ,Vand V1

(a) (b) (c)

Figure 3.4: (a) coated solid carbide (b) uncoated solid carbide (c) 450 FCD cast Iron

In order to carry out this experiment, the four factor of each parameter must be conduct and set up. Table 3.4 shows approximate for each single test run using the recommended criteria under recommendation test condition for end milling.

Table 3.4: Recommended criteria test condition for end milling

Cutting Condition						
I	Spindle Speed ,V (rev/min)	1000	1487	2015	2495	3026
II	Feed Rate, f (mm/min)	120	165	375	520	720
III	Depth Of cut (mm)	0.75	1.25	1.75	2.50	3.50
IV	Radial depth of cut (mm)	5	10	15	20	
V	Machining Length (mm)	150	300	450	600	750
VI	Machining Time (sec)	60	120	180		

Table3.5: Experimental detail of the machining trial variation of a) Spindle Speed b) Feed Rate c) Depth of Cut d) Radial Depth of Cut e) Machining Length f) Machining Time

Spindle Speed (rev/min)	1000	1487	2015	2495	3026
Feed Rate (mm/min)	165				
Depth of cut (mm)	1.25				
Radial depth of cut (mm)	20				

(a)

Spindle Speed (rev/min)	3026				
Feed Rate (mm/min)	120	165	375	520	720
Depth of cut (mm)	1.25				
Radial depth of cut (mm)	20				

(b)

Spindle Speed (rev/min)	3026				
Feed Rate (mm/min)	120				
Depth of cut (mm)	0.75	1.25	1.75	2.50	3.50
Radial depth of cut (mm)	20				

(c)

Spindle Speed (rev/min)	3026			
Feed Rate (mm/min)	120			
Depth of cut (mm)	0.75			
Radial depth of cut (mm)	5	10	15	20

(d)

Spindle Speed (rev/min)	3026				
Feed Rate (mm/min)	120				
Depth of cut (mm)	0.75				
Radial depth of cut (mm)	20				
Machining Length (mm)	150	300	450	600	750

(e)

Spindle Speed (rev/min)	3026		
Feed Rate (mm/min)	120		
Depth of cut (mm)	0.75		
Radial depth of cut (mm)	20		
Machining Time (sec)	60	120	180

(f)

3.6 EXPERIMENTAL METHOD

Step 1: CNC milling machine

Power up machine

1. Turn on primary power source.
2. Turns on the MAIN POWER SWITCH.
3. Release the Emergency Stop Button.
4. Turn On Air supply valve.

CAUTION:

a. Check that the air pressure in set to 5 kg/cm3 (71 PSI).

b. Check the air lubricator oil level.

c. Check the automatic lubricator oil level.

d. Check that the air dryer is ON (If this option is available).

Warming up the machine

1. Push (REPPOS) Soft Key at the General Mode Screen.
2. Select Automatic Feed Lever: X+, Y+, Z-
3. Push MEMORY Button at the Operator Panel.
4. Push PROG Button at the Operator Panel.
5. Push RESET Button at the Operator Panel.
6. Call program: input O1000 (Dry run Program).
7. Push O SRH Button at the Operator Panel.
8. Confirm the program OK.
9. Push CYCLE START Button at the Operator Panel.
10. Rotate the Rapid Feed Override button to 25%.
11. Rotate the Cutting Feed Override button to 100%.

Start experiment

1. Clamp the workpiece (FCD 450 Cast iron) specimen on the 3-axis Makino KE55 CNC milling machine. (When clamping a specimen on the worktable of milling machine, the table and the specimen should be free from a dirt and burrs so that the milling process not be affected.
2. Run the machine by using the parameter that has been selected based on parametric study before. The control parameter that need to be used can be referring Table 3.5.
3. Firstly, the uncoated solid carbide tool is selected and continue with coated solid carbide tool.
4. Video for this experiment was recorded for comparison between this difference tools.
5. After finish the machine part, the reading of power consumption and surface roughness of specimen is taken and recorded in the table form.

Step 2: Power consumption measurement

1. The power meter is connected at the CNC KE55 milling machine.
2. The data and result from the power meter display is collected for total active power energy with time (kWh) by using Power meter model 3600 as shown in Figure 4.6.
3. The relationship graph between cutting condition and the average power consumption is plotted.

Step 3: Surface roughness measurement

The step for using these instrument (surface tester instrument) is:

1. ISO 1997 of surface roughness is set up at the surface tester instrument.
2. The specimen is put on the instrument table.
3. The surface roughness is measured after every pass of each test by using surface roughness measurement by Mitutoyo surftest SJ-301 as shown in Figure 4.4.
4. Surface roughness measurements were recorded along the centreline of the slot cut at three locations within each slot, at the entry, middle and exit points
5. All the data is recorded to do analysis of the average surface roughness.
6. The graph relationship between cutting condition and average surface roughness is plotted.

Power off machine

1. Check the lamp on CYCLE START button off.
2. Select a Manual MODE ON THE Pendant Control Station. 28
3. Press the POWER OFF button of the Pendant control station to turn off the power of the CNC unit.
4. Turn off main power switch at the MTC cabinet

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter discusses all the result obtained after conducting the experiment. The results will be expressed in the table, graph and figures. Detail explanation of graph and figures were provided in this chapter. The data collected after dry milling process has been tabulated and analysed which are the surface roughness and power analyser. The optimum condition parameter of milling result were obtained based on detail study of Origin Pro8 software. In this project, Origin Pro8 is software used in order to find the graph and the optimum machining parameter condition for dry end mill processing. The CNC milling machine is used to machine the cast iron block. The cutting condition were selected by referred to the tool supplier and survey from the previous researcher. This Figure 4.2 and 4.3 show the close-up view of experimental set up for coated and uncoated carbide tool.

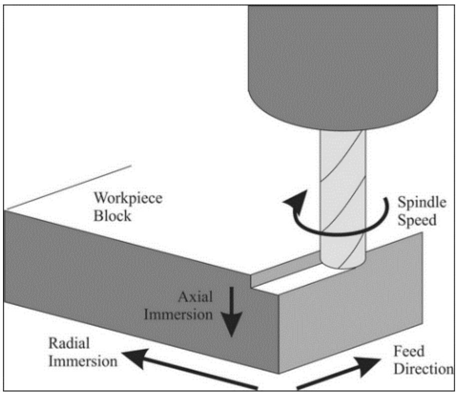
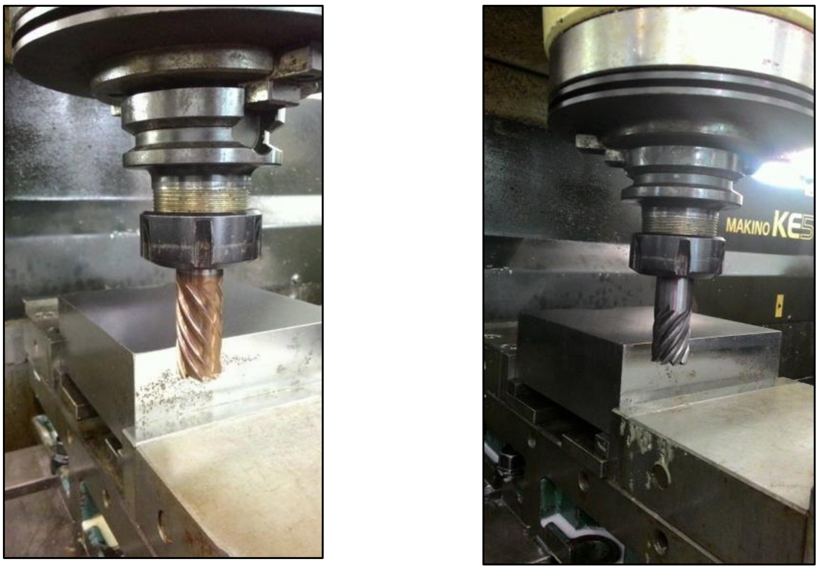


Figure 4.1: Closed –up view of experimental set up for carbide tool.

Sources: (Mohammed T. Hayajneh et. al., 2007)



(a) (b)

Figure 4.2: Closed –up view of experimental set up for (a) coated and (b) uncoated solid carbide tool.

4.2 SURFACE ROUGHNESS ANALYSIS

The data collected from this research is average surface roughness measurement. The surface roughness is measured after every pass of each test by using surface roughness measurement by Mitutoyo surftest SJ-301 profilometer at traverse length of 150 mm along centerline of sampling. Each R_a measurement is repeated at least three times. This collected data have been tabulated by followed the parametric study that was using during the experiment. Irregularities of material from machining operations is called as surface roughness and Ra is the arithmetic average value of departure of the profile from the mean line throughout the sampling length and its important factor in controlling machining performance. Material used in this experiment is FCD 450 Cast Iron block. All 180 experiments were carried out for both coated and uncoated cutting tools. The set-up of measurement is as shown in Figure 4.3.

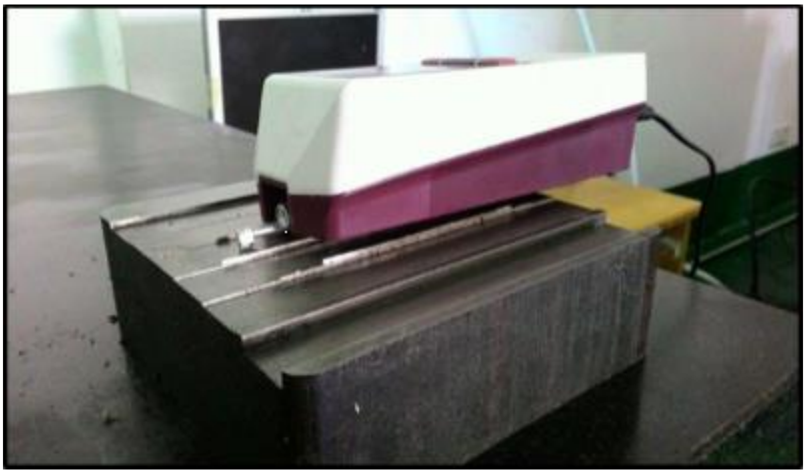


Figure 4.3: View of surface roughness measurement

4.3 POWER ANALYZER

Reduction of power consumption is one of the most industry's requirement now day. Machine tool manufacturers could contribute to this matter by developing advanced functions for machines. Power consumption of machining centre was measured in various conditions. Several of experiments were performed to verify these methods and promising results were achieved.

To order the test validity of the suggested cutting power model, lot of experiment were carried out. The group of cutting condition was designed to investigate the first optimum parameter so the six experiment will conduct according the optimum parameter to get the best of cutting condition result. After 180 specimen were carried out for experiment purposed, the active power consumption were measured for coated and uncoated carbide tool. All data collected were analysed using parametric study with the dependent variable are cutting speed, feed rate ,depth of cut, radial depth of cut, machining time and machining length. The value of optimum parameters was identified to get the minimum average power consumption.

The Figure 4.1 shows the result for power analyser. The set-up of measurement is as shown in Figure 4.4.Whereas, Figure 4.5 shows power meter model 3600 set up at the CNC Milling machine KE55.

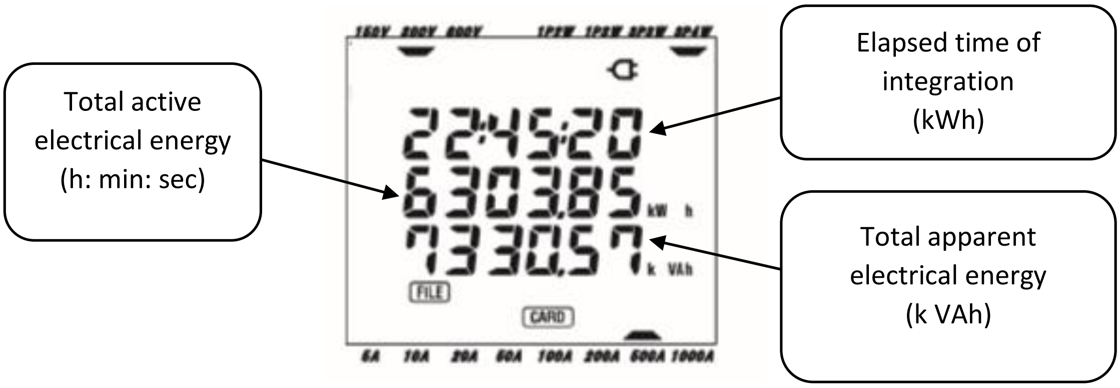


Figure 4.4: Result for power analyser on the screen

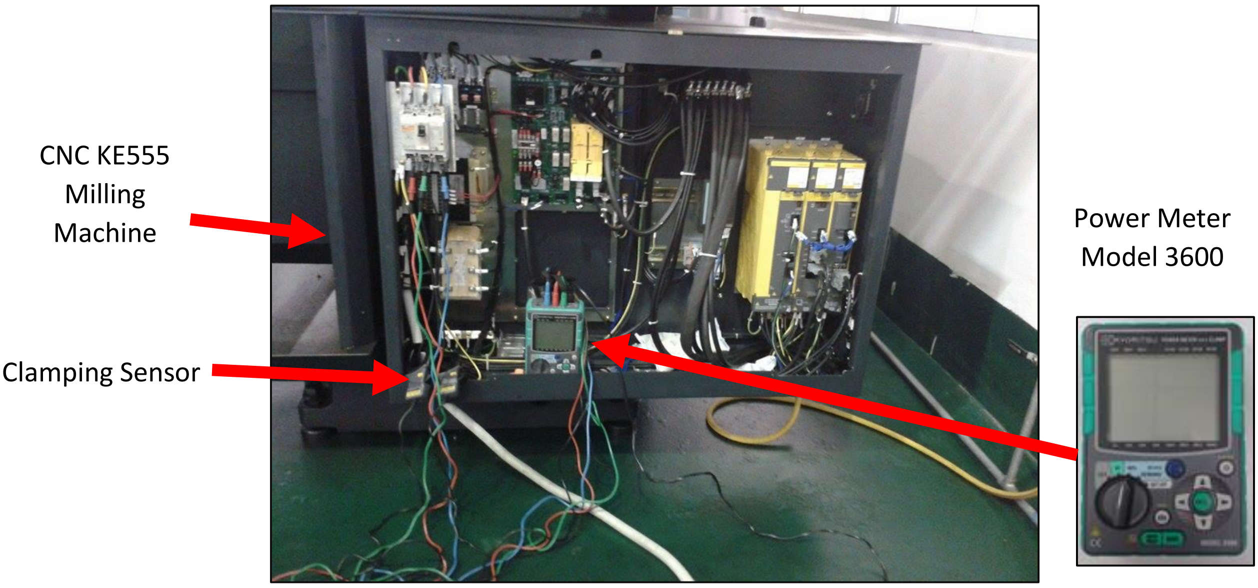


Figure 4.5: Power Meter Model 3600 set up at the CNC Milling Machine KE55

4.4 RESULT OF CUTTING CONDITION TO AVERAGE SURFACE ROUGHNESS

4.4.1 Spindle Speed

In this experiment, it is found that surface roughness decrease with an increasing in spindle speed. This result is because at low spindle speed, friction between the work-piece and the cutting tool is high due to discontinuous chips formed which are deposited in the workpiece and tool interface. (Ojolo Sunday et. al., 2015). This high friction existing in the tool-chip interface and workpiece-tool interface leads to interruptions during cutting operations, high force in machining, more energy, high temperature (heat) and leading to a poor surface quality. This result is also confirmed by (Mohammed et. al., 2007) study on the effect of machining parameters on end milling. (Ojolo Sunday et. al., 2015) observed that surface roughness values decreases as the spindle speed increases. But as the cutting feed is increased, the roughness values increases and then decreases with increase in spindle speed. (Kuram et. al., 2013) obtained similar results that increase in spindle speed reduces roughness values.

Figure 4.6 show relationship between the average surface roughness and cutting speed for coated and uncoated carbide tools. The feed rate, depth of cut (DOC), and radial depth of cut are set as constant value 165 mm/min, 1.25 mm and 20 mm for whole experiment. Two different sets of average surface roughness measurements are obtained. The average value of surface roughness for uncoated carbide end mill decreased from 2.322 µm to 1.268 µm and for coated decrement start from 0.909 µm to 0.524 µm. The average surface roughness decrease with increasing the spindle speed. Note that this is the data point with the worst (highest) surface roughness value is at the 1000rev/min for both coated and uncoated tools. 3026 rev/min is chosen as the best spindle speed with the lowest surface roughness. The graph in figure 4.6 shows the average surface roughness is lower when using coated compare to uncoated solid carbide end mill. (Sonawane Gaurav et al., 2011 found coated tools show better surface finish than uncoated tools.

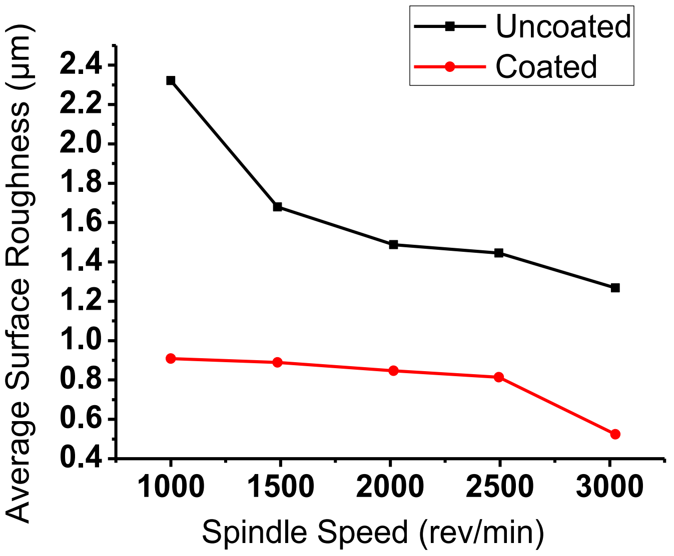


Figure 4.6: Effect of cutting speed to average surface roughness for coated and uncoated carbide tools.

4.4.2 Feed Rate

This experiment investigates the effect of feed rate on end milling of FCD 450 cast iron so as to predict the surface roughness. All this machining parameter (cutting speed, depth of cut, and radial depth of cut) are set as constant for whole experiment. From figure 4.7, two different sets of average surface roughness measurements are obtained. The average surface roughness increase with increasing the feed rate. (Sonawane Gaurav et al, 2011) stated feed is found to be the most effective as far as surface roughness is considered. (Nagi et al, 2008) also described that surface roughness is more sensitive to the feed rate and the depth of cut.

The average value of surface roughness for uncoated tool increased from 0.796 µm to 2.432 µm and for coated tool the surface roughness increasing from 0.781 µm to 1.230 µm. The result shows the coated carbide has lower average surface roughness compare to uncoated carbide same as the theoretical test that found feed rate increase will affect the average surface roughness rougher. The average surface roughness is better, when using coated carbide end mill compare to uncoated solid carbide end mill. The best feed rate is 120 mm/min for both type of cutting tool with lowest surface roughness.

Combination of high cutting speed and low feed rate using coated solid carbide produce better surface finish compare use uncoated solid carbide tool. (Liew et. al., 2008) found that while machining coated tools exhibit higher wear resistance that uncoated one, highest flank wear was found at the flank face near the DOC zone.

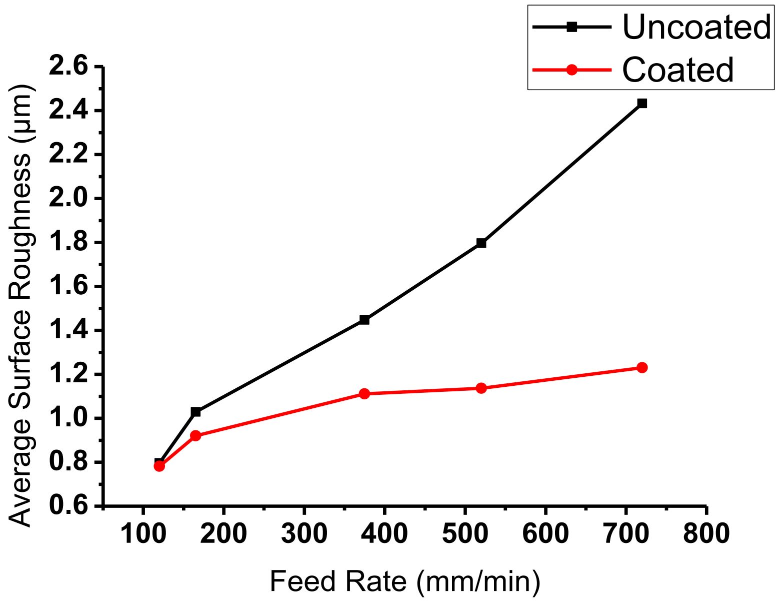


Figure 4.7: Effect of feed rate to average surface roughness for coated and uncoated carbide tools

4.4.3 Depth of Cut

Figures 4.8 show the relationship between surface roughness and depth of cut at constant cutting speed, feed rate and radial depth of cut. The graphs give an insight on how the surface responds with change in depth of cut for both coated and uncoated solid carbide end mill. From the result, it is observed that an increase in the depth of cut has high effect on the surface roughness of the FCD 450 cast iron block. Therefore a very large depth of cut leads to a poor surface finish. This result agrees with that obtained by (Sonawane Gaurav et al., 2011) that an increase in the depth of cut has little effect on the surface roughness.

From Figure 4.8, surface roughness value increased from 0.796 µm to 1.837 µm as the depth of cut is increased 0.75 mm to 3.50 mm at constant spindle speed of 3026 rpm for uncoated cutting tool. The increase in surface roughness is expected because the width of contact between the material and cutting tool is more, giving rise to fiction between the workpiece and tool, leading to interruption in cutting operation. More force and energy will be required for the cutting operation and eventually affecting the surface roughness (poor surface quality) (Sonawane Gaurav et al., 2011). The best depth of cut with the lowest surface roughness for both tools is 0.75 mm. The result shows the coated carbide has lower average surface roughness compare to uncoated carbide same as the theoretical test that found surface roughness increases with an increase in depth of cut.

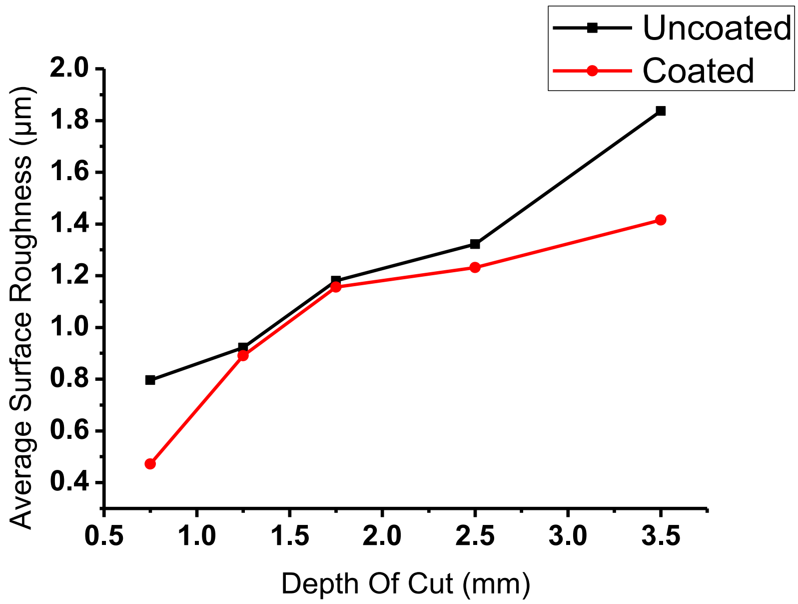


Figure 4.8: Effect of depth of cut to average surface roughness for coated and uncoated carbide tools

4.4.4 Radial Depth of Cut

In Figure 4.4, the graphs are drawn showing the difference of surface roughness with radial depth of cut. It is observed that surface roughness increases with increase in radial depth of cut for both type of cutting tool. It is observed radial depth of cut of 20 mm has the highest surface roughness in the range of 1.034 µm for uncoated solid carbide, followed by radial depth of cut 15 mm,10 mm (0.922 µm,0.814 µm) and the lowest is 5 mm (0.799 µm , respectively. Whereas for the coated the highest surface roughness at 20 mm (0.922 μm). Radial depth of cut is one of the mainly dominant on surface quality of finished part. Instead of using larger value of radial depth of cut, it is better to increase axial depth of cut if higher values of machining parameters such as spindle speed and feed rate are needed to increase production rate, as which can give better surface quality and reduce hand work. The result shows the coated carbide has lower average surface roughness compare to uncoated carbide.

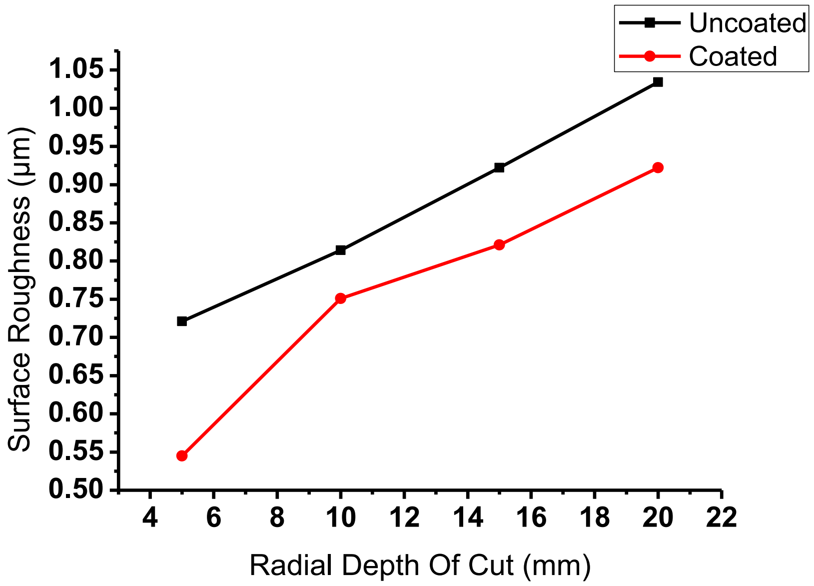


Figure 4.9: Effect of radial depth of cut to average surface roughness for coated and uncoated carbide tools

4.4.5 Machining Time

The main parameters that affects surface roughness have been identified analysed under different conditions and finally optimized. (Sonawane Gaurav et al., 2011) found using coated tool failure occur at short machining time in comparison uncoated tool runs for a machining time much longer than coated tool. This data set is for the run with a spindle speed of 3026 rpm with depth of cut 0.75mm, feed rate 120 mm/min and radial depth of cut 20 mm.

Figure 4.10 shows the longer the machining time the higher the surface roughness of the 450 FCD cast iron for both coated and uncoated end mill cutting tool. For milling process it can be seen from figure 4.10 that uncoated tool run for 180 second has the highest surface roughness (1.344 µm) compare 180 second for coated with surface roughness (0.781 µm). Good quality surface finish for coated tools is better compare uncoated tool with decreasing of machining time. (Sonawane Gaurav et al., 2011) stated that coated tools showed better surface finish than uncoated due to less coefficient of friction and lower thermal conductivity of coating.

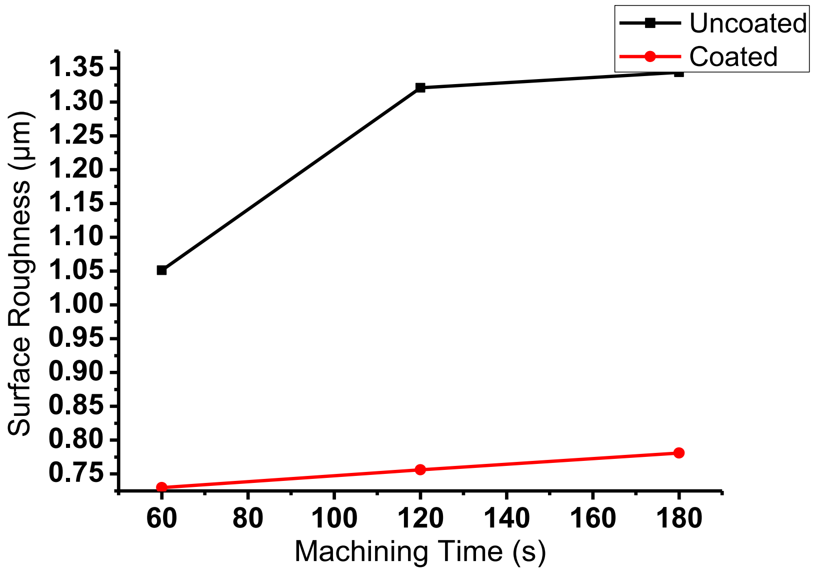


Figure 4.10: Effect of machining time to average surface roughness for coated and uncoated carbide tools

4.4.6 Machining Length

Figure 4.11 shows the relationship between average surface roughness and the machining length. The constant value for cutting speed, feed rate, depth of cut and radial depth of cut are 3026 rpm, 120mm/min, 0.75 mm and 20 mm is set up for this experiment. Five difference machining length are used for this experiment (150,300,450,600,750) mm. There are big difference between coated and uncoated result of surface roughness about 63.85%. Better quality surface finish is observed for coated tools, especially with decreasing of machining time. (Sonawane Gaurav et al., 2011) found uncoated tools the surface defect occurs at a short distance which causes to increase the Ra value. For coated tools wear is less so Ra value appears for longer distance i.e. reduces Ra values. At the graph in figure 4.11 shows, the average surface roughness for coated is a round (0.424-0.472) µm and for uncoated surface roughness (0.894-0.983) µm. The optimum machining length is at 300 mm for both coated and uncoated solid carbide tools.

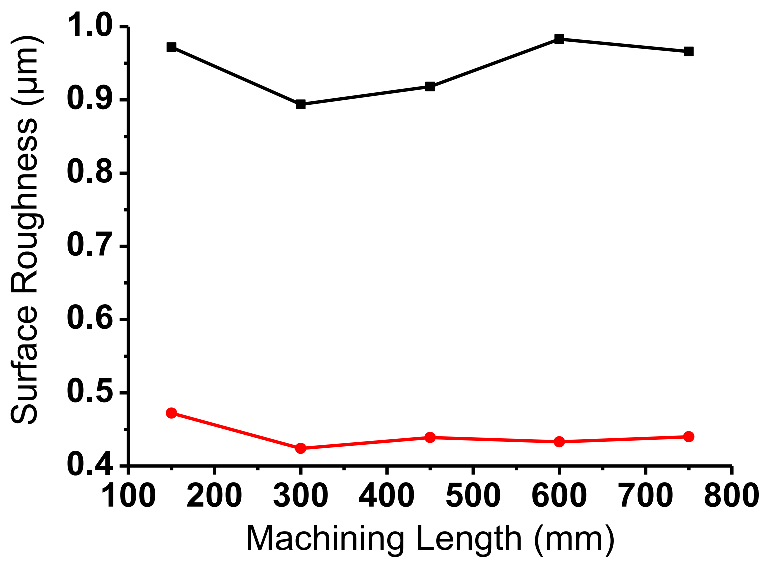


Figure 4.11: Effect of machining length to average surface roughness for coated and uncoated carbide tools

4.5 RELATIONSHIP BETWEEN CUTTING CONDITIONS ON SURFACE ROUGHNESS

Increasing the productivity and the quality of the machined parts are the main challenges of metal-based industry. One of the most importance aspect in engineering process is to get the high quality of product. So the surface finish is vital in process line by term of surface roughness (Ra). The roughness average is the area between the roughness profile and its central line, or the integral of the absolute value of the roughness profile height over the evaluation length.

A controlled set of experiments is carried on rectangular FCD450 cast iron block to determine the relationship between spindle speed, feed rate, and axial depth of cut (DOC), radial depth of cut, machining length, and machining time to know the surface roughness of the workpiece. A total of 180 experiments were performed. The parameter of interest was the surface roughness at varying cutting feeds, spindle speeds and depths of cut which was measured using Mitutoyo surface tester.

Based on the conducted experiment, it is observed graph in the Figure 4.6 by increase the spindle speed, the smaller produces are decreasing the quality. Spindle speed is one of the main parameter that contribute in producing a good quality of surface roughness. This result is expected because at low spindle speed, friction between the work-piece and the cutting tool is high due to discontinuous chips formed which are deposited in the workpiece and tool interface (Ojolo Sunday et. al., 2015). This high friction existing in the tool-chip interface and workpiece-tool interface leads to interruptions during cutting operations, high force in machining, more energy, high temperature (heat) and leading to a poor surface quality. As the spindle speed is increased, there is a decrease in the coefficient of friction between the workpiece and tool interface.

At low feed rate, chip formed during the cutting operations are continuous which have less interruption between tool-chips and workpiece-tool leading to a reduced friction between workpiece-tool interfaces. As the feed is increased, chips become discontinuous and are deposited between workpiece and tool leading to increased coefficient of friction and more interruption resulting in poor surface finish (Ojolo Sunday et. al., 2015) as shown in the Figure 4.7.

Form review of axial depth of cut and radial depth of cut, increasing will increased the value of surface roughness. Base on the result in Figure 4.8 and Figure 4.9 show that the smaller the value of depth of cut, the good quality of surface roughness produced. The increase in surface roughness is expected because the width of contact between the material and cutting tool is more, giving rise to fiction between the workpiece and tool, leading to interruption in cutting operation. (Sonawane Gaurav et al., 2011) found more force and energy will be required for the cutting operation and eventually affecting the surface roughness (poor surface quality).

The effect for machining length and machining time as shown in the Figure 4.10 and Figure 4.11 are also importance especially in production line for produce high quality of the product and in the term of costing. To improve quality and increase productivity of the machined part the optimum value of machining time and machining length are choose so that the high production rate will optimum also. Average decrement **27.92%** for surface roughness by using coated compare uncoated tool.

4.6 RESULTS OF CUTTING CONDITION TO AVERAGE POWER CONSUMPTION

4.6.1 Spindle Speeds

From the graph it was found that as the spindle speed increases, power consumption values also increases. (Andy and Jonathan, 2013) found, increase in spindle speed leads to a direct increase in MRR, and substantial increase in peak power levels during cutting process. Figure 4.12 shows that uncoated solid carbide has the lowest power consumption at 1000rev/min about 2.24 kWh and coated has the lowest power consumption at 1000 rev/min about 3.85 kWh. For Uncoated tool carbide has the highest power consumption at 3026 rpm (3.15 kWh) and coated solid carbide tool has the highest power consumption also at 3026 rev/min (4.37 kWh). Its shows coated have higher power consumption compare uncoated solid carbide.

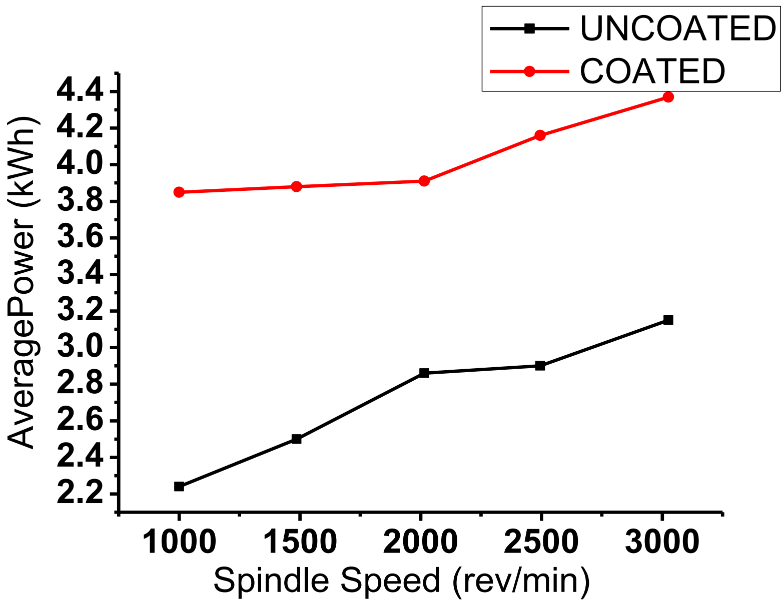


Figure 4.12: The effect of cutting speed to average power for coated and uncoated carbide tools

4.6.2 Feed Rate

In Figure 4.13 it has been found that there is a negative relationship between feed rate and power consumption at constant cutting speed (3026 rev/min), depth of cut (1.25 mm) and radial depth of cut (20 mm). It shows the slop of lines of various feed rate, power consumed by tool increases with the decreasing in feed rate. (Andy and Jonathan, 2013) found that energy consumption varies widely for each parameter and in some cases such as when we increase feed rates, can actually decrease dramatically. It was also found that at 120mm/min to 720 mm/min the highest power consumption was observed for coated solid carbide (4.4 kWh to 0.97 kWh) and (4.03 kWh to 0.25 kWh) for uncoated.

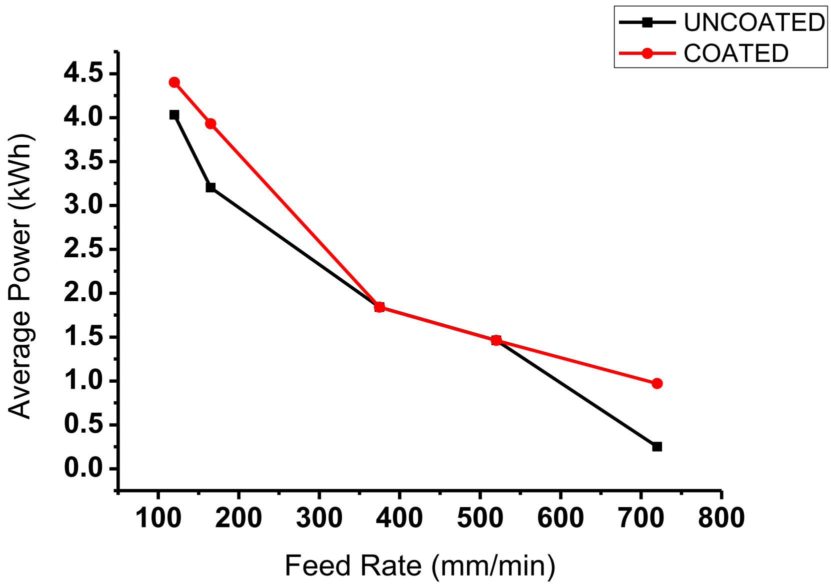


Figure 4.13: The effect of feed rate to average power for coated and uncoated carbide tools

4.6.3 Depth of Cut

The effect of depth of cut to average power for coated and uncoated carbide tools is shown in Figure 4.14. From the graph it was found that power consumed by tool increases with increase in depth of cut. (Andy and Jonathan, 2013) found that increasing the axial immersion leads to an increase in spindle power consumption. For coated and uncoated solid carbide, the highest power consumption was observed at the highest value of depth of cut. Coated tool has lower power consumption compare uncoated tool. The optimum power 5.33 kWh for uncoated and 2.73 kWh for coated solid carbide tools with (2.5 mm) depth of cut.

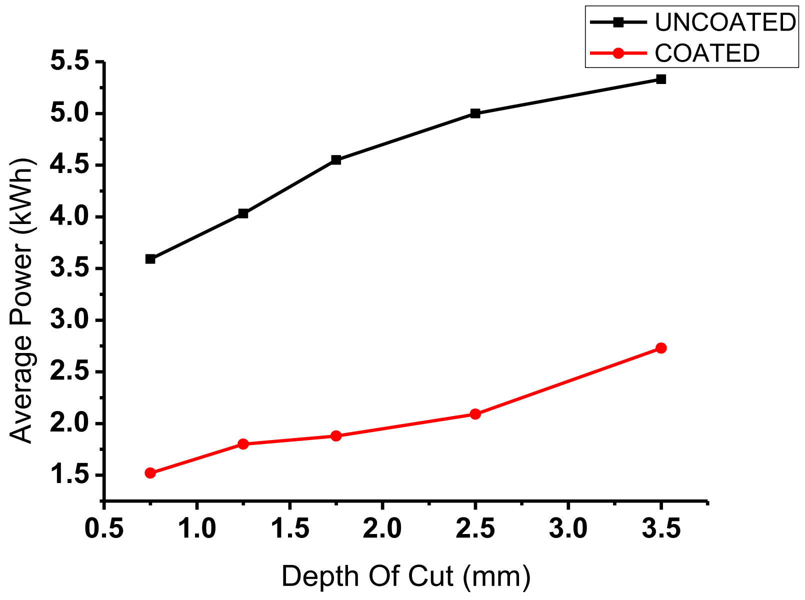


Figure 4.14: The effect of depth of cut to average power for coated and uncoated carbide tools

4.6.4 Radial Depth of Cut

From the radial depth of cut results Figure. 4.15, there would appear to be a linear relationship between power consumption and depth of cut for this specific coated and uncoated tools and FCD cast iron workpiece. Increases in radial depth of cut will increase the chip load along a single cutting edge. (Andy and Jonathan, 2013) found that increasing the radial immersion leads to a spindle power consumption increase. The result shows coated have smaller power consumption (1.47 kWh to 1.52 kWh) compare for the uncoated (3.21 kWh to 3.59 kWh). The same, values are significantly high to more than 3 kWh for uncoated material. If the radial depth of cut increases enough, the number of contact points between cutting edges and the workpiece could increase, leading to a rise and subsequent increase in power requirements for machine tool. Each time there is a new contact point between a cutting edge and the workpiece material, the power consumption as a result of radial depth of cut will increase.

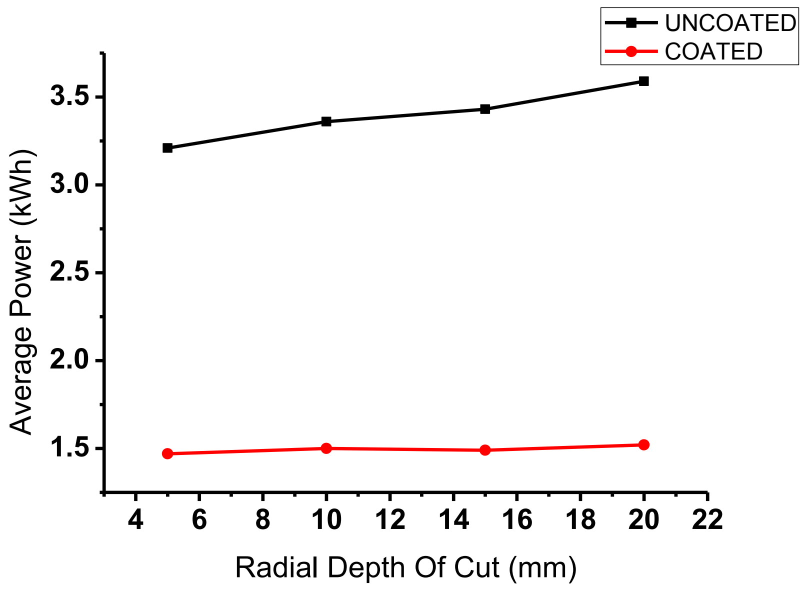


Figure 4.15: The effect of radial depth of cut to average power for coated and uncoated carbide tools

4.6.5 Machining Time

Figure 4.16 show the longer the machining time the higher the power consumption of the FCD450 cast iron for both coated and uncoated end mill cutting tool. This data set is for the run with a rotational speed of 3026 rpm with depth of cut 0.75 mm, feed rate 120 mm/min and radial depth of cut 20 mm. For milling process it can be seen from figure 4.12 that uncoated tool run for 180 second has the highest power consumption (5.63 kWh) compare 180 second for coated (5.11 kWh). Power consumption for coated tools is lower compare uncoated tool with decreasing of machining time. Power consumption for coated tools is lower compare uncoated tool with decreasing of machining time.

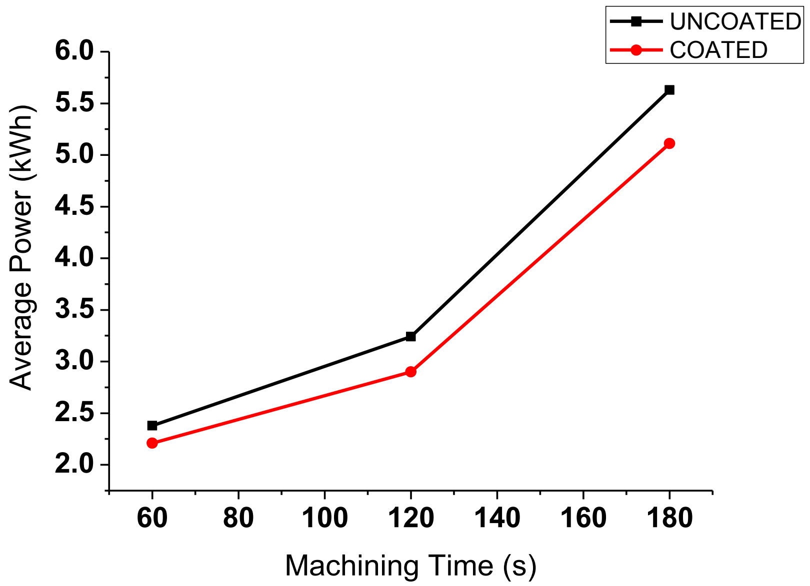


Figure 4.16: The effect of machining time to average power for coated and uncoated carbide tools.

4.6.6 Machining Length

By analysing power data of Figure 4.17 coated solid carbide give lower power consumption than that uncoated solid carbide. Besides that, surface roughness was rather smooth for coated even when machining length decreased. On the whole, coated tool ensure the better surface quality of product and lower power consumption compare uncoated solid tool. The same incensement for both result coated and uncoated tools which are the power is directly proportional to the machining length. For coated tool solid carbide has lower power consumption 1.52 kWh to 7.59 kWh at constant spindle feed of 120 mm/min, 3026 rev/min with 0.75 mm axial depth of cut. Whereas the uncoated solid carbide power consumption (3.59 kWh to 17.92 kWh). Besides that, uncoated have greater gradient slop about 0.0238 compare coated only 0.0099.

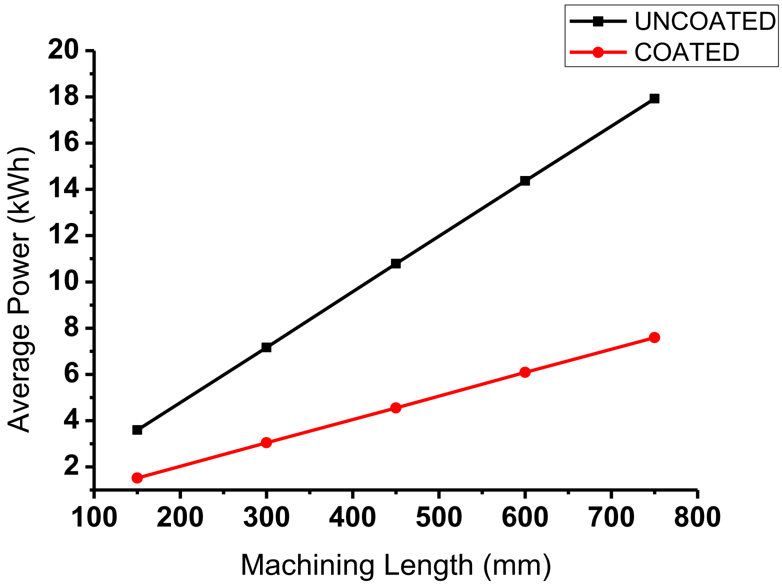


Figure 4.17: The effect of machining length to average power for coated and uncoated carbide tools.

4.7 RELSTIONSHIP BETWEEN CUTTING CONDITIONS ON POWER CONSUMPTIONS

Power consumption is an importance factor to be considered in milling operation and the study of power consumed by the tool helps to find out the life of the tool for maximum productivity, helps to select the capacity of the motor required for the machine and it also helps for designing machine components. (Mannan et. al., 1989) and (Cuppini et. al., 1990) were two of the first groups of researchers to actively monitor machine tool power in turning and milling, respectively, concluding that power signals are highly effective at detecting tool breakage, but reasonably insensitivity to continual tool wear. Modifying the cutting conditions will reduces energy consumption by using optimum cutting parameter such as cutting speed, feed rate, depth of cut and radial depth of cut.

This study investigated the parameter optimization of CNC milling operation for FCD 450 cast iron. One of the first studies to examine energy usage of computer numerical controlled (CNC) machines was done by (Filippi A.D et. al., 1981). This study found that the largest loss of efficiency in machining was due to machine under-utilization. Spindle speed (rev/min), feed (mm/min), axial depth of cut (mm), and radial depth of cut (mm) are optimized for power consumption as performance characteristic. Comparison between coated and uncoated is also applied to identify most significant factor. For uncoated and coated result, power consumption increase with increase in spindle speed (1000 rev/min to 3026 rev/min) depth of cut (0.75 mm to 3.50 mm), and feed rate (120 mm/min to 720 mm/min). Increase in radial depth of cut shows moderate increase in power consumption radial depth of cut (5 mm to 20 mm). Refer Figure 4.12 to 4.17.

(Andy and Jonathan, 2013) found, increase in spindle speed leads to a direct increase in MRR, and substantial increase in peak power levels during cutting process. (Andy and Jonathan, 2013) found that energy consumption varies widely for each parameter and in some cases such as when we increase feed rates, can actually decrease dramatically. (Andy and Jonathan, 2013) also found that increasing the axial and radial immersion leads to a spindle power consumption increase. From the result it was found that power consumed by coated solid carbide lesser compare by using uncoated solid carbide tool. Average decrement **9.32%** for power consumption by using coated compare uncoated tool.

4.8 EFFECT OF CUTTING CONDITIONS TO SURFACE ROUGHNESS AND POWER CONSUMPTION FOR SOLID CARBIDE TOOL

4.8.1 Spindle Speed

This study investigated the multi-performance optimization of milling process for an optimal parametric combination to yield the minimum surface roughness with the minimum power consumption using experimental double Y axis graph. Figure 14.8 shows the effect of cutting speed to average surface roughness and average power for coated solid carbide. Thus, the optimum cutting condition was found at cutting speed (2587.95 rev/min) with average power (4.1968 kWh) and average surface roughness (0.7638 µm).

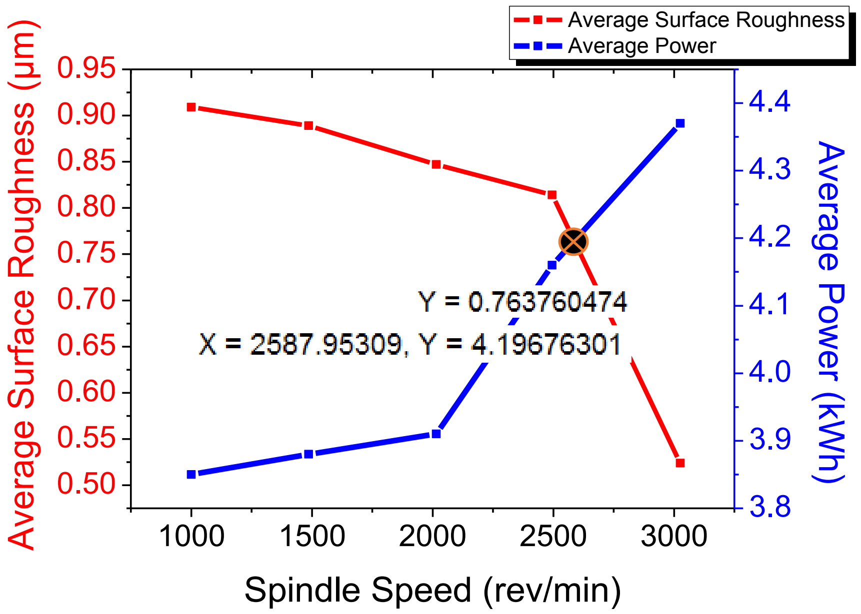


Figure 4.18: The effect of spindle speed to average surface roughness and average power for coated solid carbide.

4.8.2 Feed Rate

Good surface finish is observed for coated tools, especially when combination of high speed and low feed rate is used (Ghani et al, 2004). Figure 4.19 shows the effect of feed rate to average surface roughness and average power for coated solid carbide. The optimum value from this experiment was found at feed rate (280.2772 mm/min) with average power (2.7749 kWh) and average surface roughness (1.0244 µm).

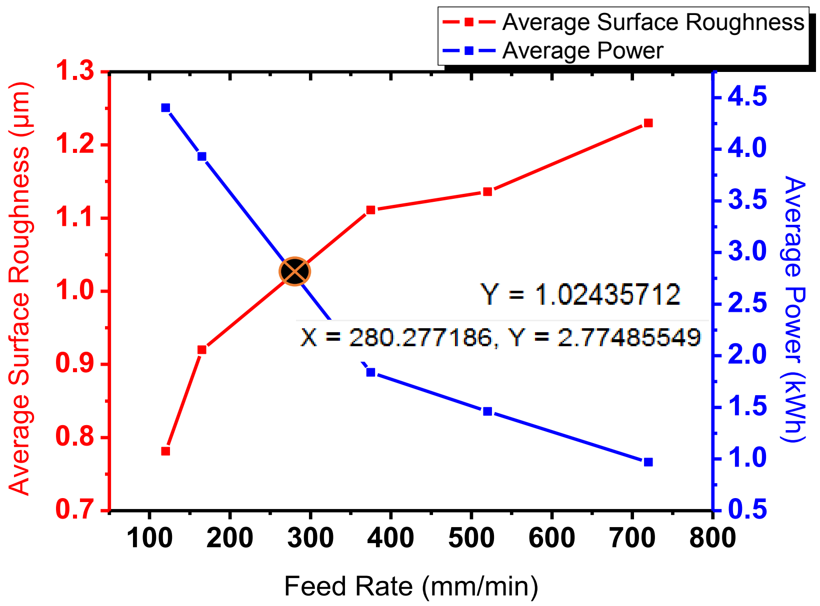


Figure 4.19: The effect of feed rate to average surface roughness and average power for coated solid carbide.

4.8.3 Depth of Cut

The experimentally measured depth of cut readings is used to plot power consumption and average surface roughness. From the graph above, it was found that power consumed by the tool increases with increase in depth of cut as well increasing of average surface roughness. Best surface roughness and power used value are obtained at low value depth of cut. The optimum power consumption at the lowest depth of cut (0.75 mm) with (1.5 kWh) of power consumption and (0.472 µm) surface roughness.

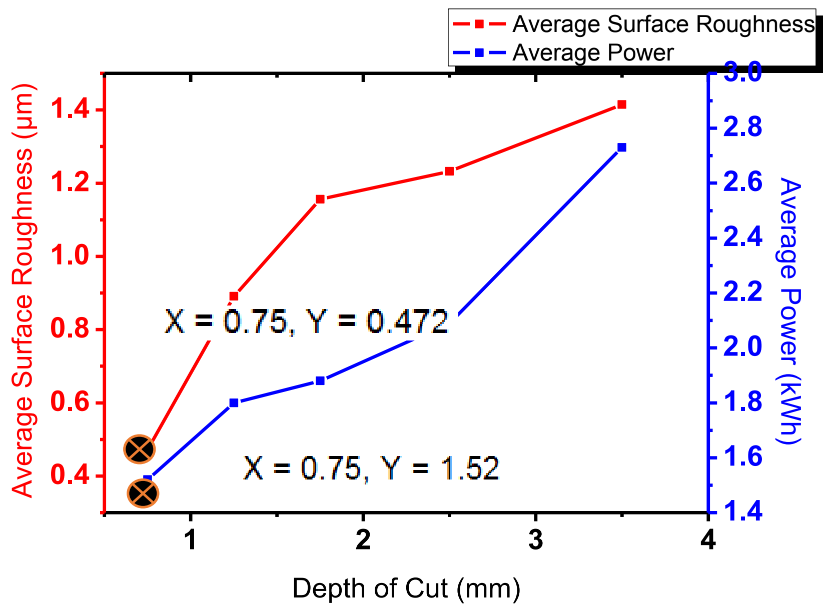


Figure 4.20: The effect of depth of cut to average surface roughness and average power for coated solid carbide.

4.8.4 Radial Depth of Cut

The experimentally measured depth of cut readings is used to plot power consumption and average surface roughness. From the below plot (Figure 4.21), it is noticed that though the surface roughness and power consumption generally increases with an increase in radial depth of cut. The optimum value from this experiment was found at radial depth of cut (10.8845 mm) with average power (1.4981kWh) and average surface roughness (0.7630μm).

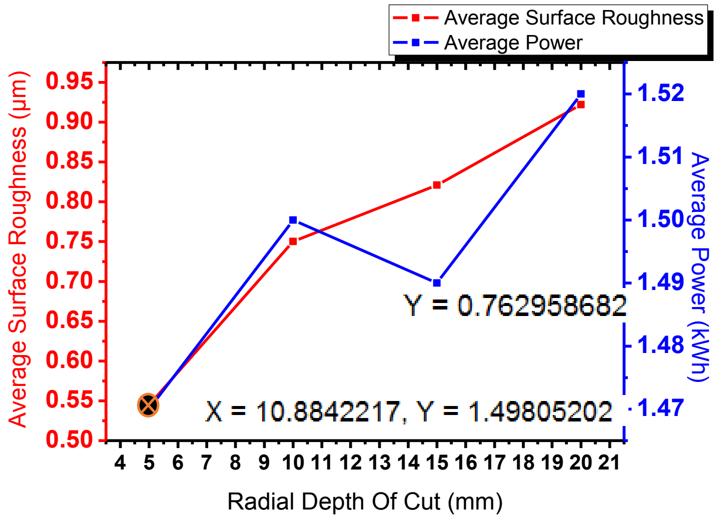


Figure 4.21: The effect of radial depth of cut to average surface roughness and average power for coated solid carbide.

4.8.5 Machining Time

The effect of machining time to average surface roughness and average power for coated solid carbide is shown in Figure 4.22. From the graph it was found that as the machining time increases, power consumption values also increases. Its shows the optimum parameter was found at machining time (73.5second) with average surface roughness (0.7356 µm) and power consumption (2.3503 kWh).

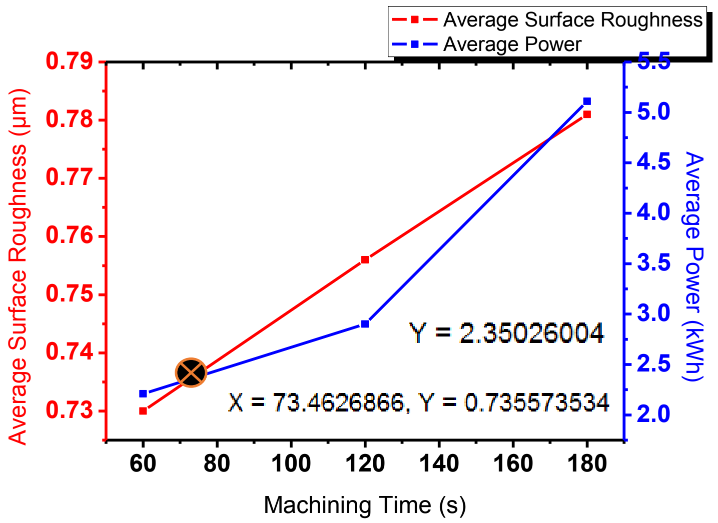


Figure 4.22: The effect of machining time to average surface roughness and average power for coated solid carbide.

4.8.6 Machining Length

Figure 4.23 shows the effect of machining length to average surface roughness and average power for coated solid carbide. Therefore, interpretations may be made according to cutting parameter. In determining optimum cutting conditions of experiments to be conducted under the same conditions for machining length (269.4 mm) with average surface roughness (2.7428 µm) and power consumption (0.4335 kWh).

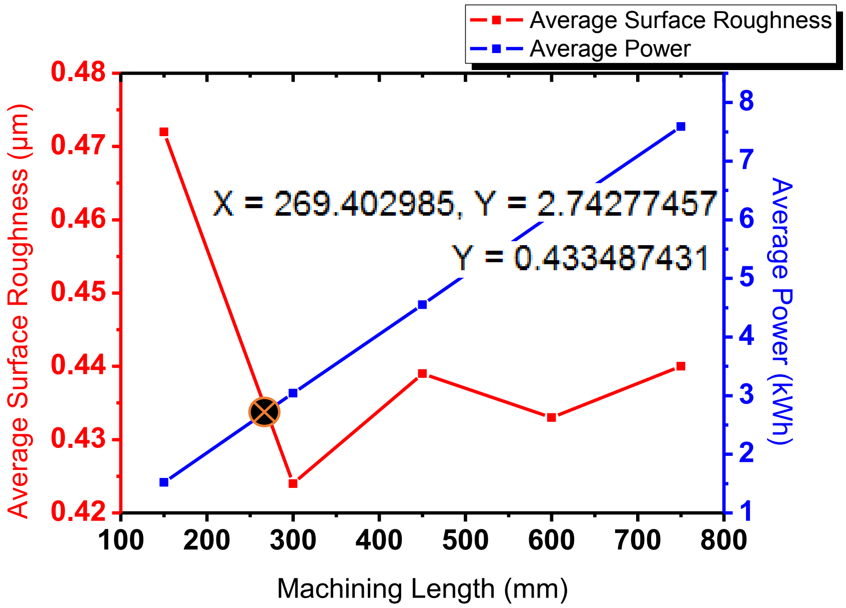


Figure 4.23: The effect of machining length to average surface roughness and average power for coated solid carbide.

4.8 DISCUSSION

From this chapter, the minimum average surface roughness is shown by coated solid carbide cutting tool compare uncoated solid carbide cutting tool. (Sonawane Gaurav et. al., 2011) found that coated tools show better surface finish than uncoated tools. This is due to the reason that when uncoated tools are used for machining, the work material adhere on to the machined surface because of more tool wear.

The experimental output indicated for feed rate, depth of cut, radial depth of cut, machining time and machining length as this cutting parameter increase the average surface roughness also increase. (Mohammed et. al., 2007) stated that the most important interactions, that effect surface roughness of machined surfaces, were between the cutting feed and depth of cut, and between cutting feed and spindle speed. For the spindle speed it inverse which the increase of cutting parameter value will result decreasing the average surface roughness. As the spindle speed is increased, there is a decrease in the coefficient of friction between the workpiece and tool interface (Ojolo Sunday et. al., 2015).

Generally, at the combination of low cutting speed, feed rate and depth of cut resulted better tool life and better surface roughness; (Ghani et al, 2004) obtain similar result when machining the cast iron. The ductile cast iron has good mechanical properties, and is widely used for parts of automobiles, construction machinery, machine structure and so on (Morrogh.H, 1948).

All machining parameter is necessary to be responsible for smooth surface roughness $R_{a.}$ it is well suggested to get high quality of surface finish by using the lower feed rate, higher spindle speed, lower depth of cut, radial depth of cut to get the optimum result. Thus these parameter are adjusted to desire value and the parameter set is created. By considering all this machining parameter, spindle speed, feed rate, depth of cut has been established as most influencing parameter, followed by machining time and machining length.

The surface roughness in milling depend on the feed rate (Martelotti, 1941).Actually, the influence of the spindle speed on the work-piece surface roughness is complex and its quite depend on the material properties of the cutting tools. (Sonawane Gaurav et al., 2011) found more force and energy will be required for the cutting operation and eventually affecting the surface roughness (poor surface quality). Tools with lower hardness (coated solid carbide), the surface roughness increases as the spindle speed increases (Li & Low, 1994). In this experimental work the power consumed by the coated solid carbide tool and uncoated solid carbide tool during milling FCD450 cast iron was studied.

Based on the experimental data the experimental output indicated for cutting speed, depth of cut, radial depth of cut, machining time and machining length as this cutting parameter increase the average power consumption also increase. (Andy and Jonathan, 2013) found, increase in spindle speed leads to a direct increase in MRR, and substantial increase in peak power levels during cutting process and energy consumption varies widely for each parameter and in some cases such as when we increase feed rates, can actually decrease dramatically. For the feed rate it inverse from this trend which the increase of cutting parameter value will result decreasing the average power consumption. (Andy and Jonathan, 2013) found that increasing the axial and radial depth of cut immersion leads to a spindle power consumption increase.

From the comparison of the tools it was found that during milling of FCD450 cast iron with both tools uncoated consumes more power than the coated solid carbide tool for cutting parameter of depth of cut, radial depth of cut, machining time and machining length whereas coated consume more power by cutting speed and feed rate parameter.

CHAPTER 5

CONCLUSIONS AND RECOMENDATIONS

5.1 INTRODUCTION

This chapter presents the interpretation and summary of the study in several sections. The first section gives a concise overview of the study, including methodology and findings in relation to the research questions and hypotheses. Then, based upon the discussion of the findings in Chapter 4 the conclusion section places the whole research within the web-based library service quality measurement context. Finally, the third section discusses the implications for library practitioners, research limitations and directions for future research.

5.2 CONCLUSIONS

From the results and analysis of the experiments, it can thus be concluded that the surface roughness (Ra) of a machined surface whether using coated and uncoated solid carbide tools predicted effectively by combining six of these parameters- cutting speed, feed rate, axial depth of cut, radial depth of cut, machining length and machining time. It can also be concluded that using coated will reduce the surface roughness value better when compared uncoated solid carbide tool. Surface roughness values were affected mostly by axial depth of cut, followed by feed rate, cutting speed, radial depth of cut, machining time and machining length has the least impact on surface roughness values.

According to the theoretical, the result shows that cutting speed and feed rate combination has the best interaction while combination of feed rate and depth of cut has the worst interaction leading to a poor surface finish. For this experimental, effect of depth of cut to surface roughness is the worst result follow feed rate, cutting speed, radial depth of cut, machining time and lastly machining length according to increase surface roughness's . The model developed can be used to select the best combination of cutting variables for achieving optimum conditions that will result in minimum surface roughness during cutting operation.

From experimental study, it is found that from the comparison of the tools it was found that during milling of FCD 450 cast iron with both tools uncoated solid carbide consumes more power than the carbide tool for axial depth of cut, radial depth of cut, machining time and machining length parameter. Whereas cutting speed and feed rate parameter show, coated has higher power consumption compare to the uncoated solid cutting tool.

Thus, the optimum cutting condition was found at cutting speed (2587.95 rev/min) with average power (4.1968 kWh) and average surface roughness (0.7638 µm). For feed rate (280.2772 mm/min) the optimum parameter are average power (2.7749 kWh) and average surface roughness (1.0244 µm). Besides that, the optimum parameter for power consumption (1.5kWh) with (0.796 µm) of surface roughness is at the lowest depth of cut (0.75mm).

The optimum radial depth of cut is (10.8845 mm) with average power (1.4981 kWh) and average surface roughness (0.7630µm). It is also shows the optimum parameter was found at machining time (73.5second) with average surface roughness (0.7630µm) and power consumption (2.3503 kWh). In determining optimum cutting conditions of experiments to be conducted, the same conditions for machining length (269.4mm) with average surface roughness (2.7428 µm) and power consumption (0.4335 kWh).

In this experiment thus, a common consensus of these results is that, for a better surface finish and lower power consumption, feed rate needs to be reduced while cutting speed to be increased. However, for higher productivity, a maximum material removal rate is required, suggesting the increased feeds and axial depths of cut and radial depth of cut. Thus, the challenge is to maximize the feed rate as much as possible while maintaining surface roughness and optimum the power consumptions. .Results show that, the machining of FCD450 is improved by using coated tools. From the experimental investigation it is observed that coated tools give better results as compared to uncoated tools in milling.

5.3 RECOMMENDATIONS FOR FUTURE RESEARCH

From the results that have been obtained in the previous chapter, the following future works can be recommended:

1. The feed rate, cutting speed and depth of cut should be selected carefully in order to reduce all kinds of damage in end milling process of FCD 450 cast iron.
2. Used difference type of materials to study the effect of cutting tool parameter and workpiece in milling process.
3. Comprising the result with the more advance machine such as High speed machine because it will give better result rather than use a milling machine.

To reduce power consumption in machine tool operation, the major causes are investigated and studied with following findings:

1. Power consumption can be reduced for end milling by setting the cutting conditions high yet within a value range which does not compromise tool life, surface finish, there by shortening of machining time.
2. Optimum parameter is used to get better surface roughness and lower power consumption.
3. Use coated tools is more power saving compare using uncoated tools for long time process about 9.32% average power decrement.
4. Select tool geometry that will cause chips to be lifted upwards and out from the finished surface and constantly thrown clear of the cutter. Maintain sharp cutting edges so that the tools will shave the material instead of rubbing it.

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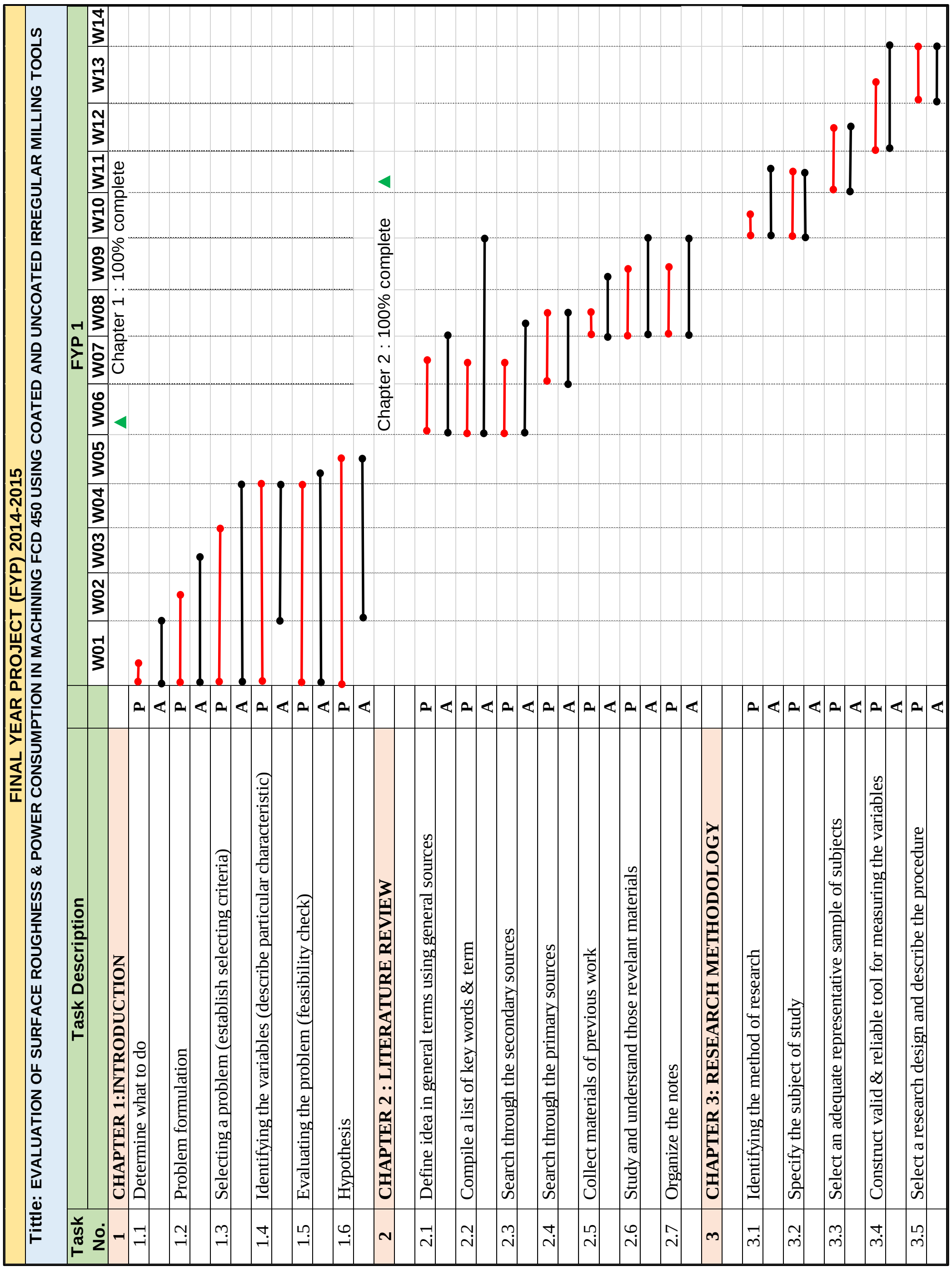
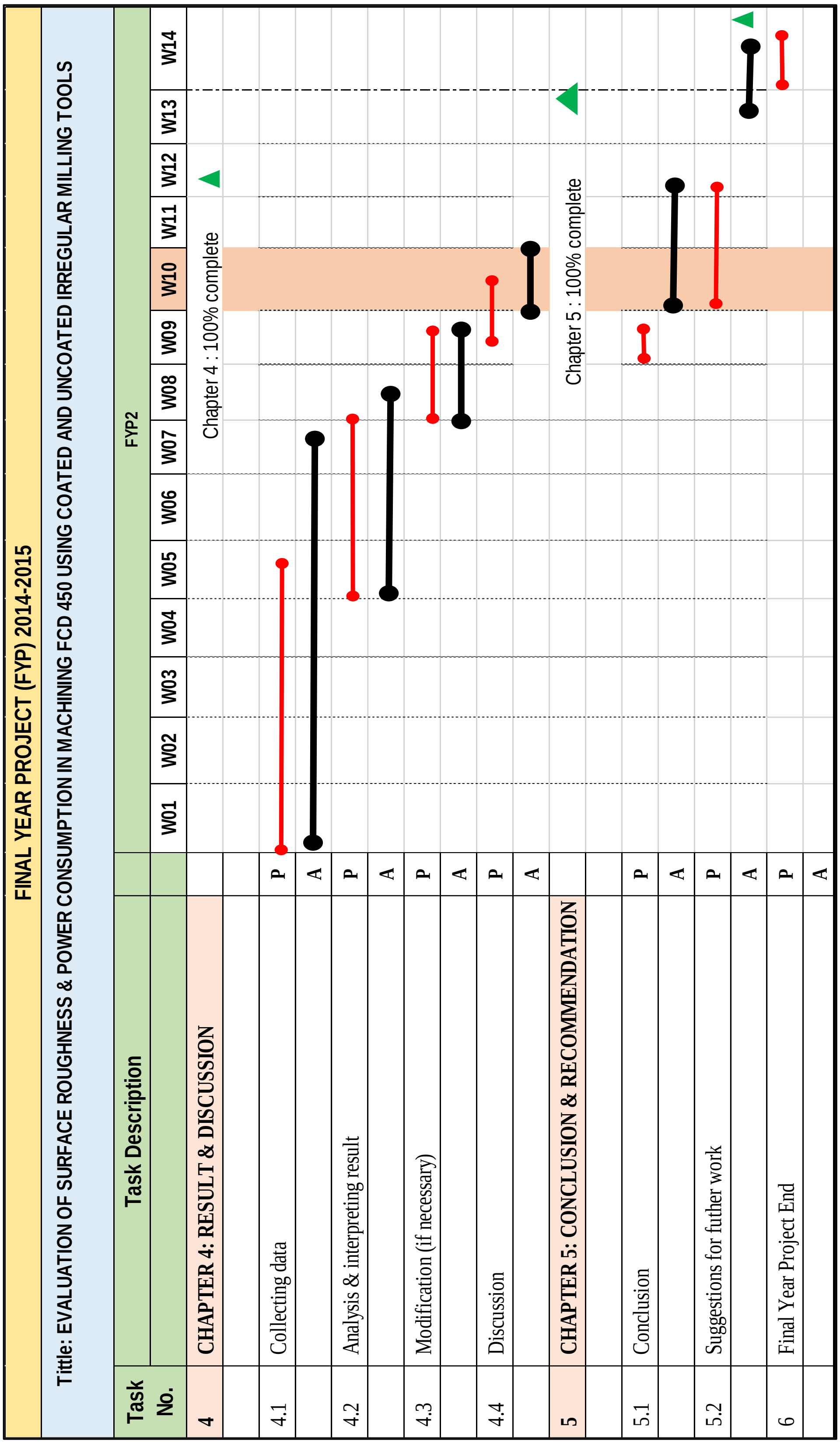
APPENDICES B

GANTT CHART

A.1 Gantt chart FYP 1



A.2 Gantt chart FYP 2



APPENDICES B
TABLE OF RESULTS

B.1 Table 4.1: Result for surface roughness of uncoated carbide tool with difference cutting speed when machining cast iron in dry condition.

Control Parameter					Result			
No. of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (µm)
1	1000	120	0.75	20	2.239	2.406	2.322	2.322
2	1487	165	1.25	20	1.710	1.778	1.552	1.680
3	2015	375	1.75	20	1.404	1.457	1.400	1.488
4	2495	520	2.50	20	3.865	3.552	5.442	1.445
5	3026	720	3.50	20	4.231	4.643	4.758	1.268

B.2 Table 4.2: Result for surface roughness of coated carbide tool with difference cutting speed when machining cast iron in dry condition.

Control Parameter					Result			
No.of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (µm)
1	1000	165	1.25	20	0.890	0.888	0.950	0.909
2	1487	165	1.25	20	1.01	0.910	0.748	0.889
3	2015	165	1.25	20	1.005	0.742	0.793	0.847
4	2495	165	1.25	20	0.723	0.810	0.910	0.814
5	3026	165	1.25	20	0.472	0.540	0.560	0.524

B.3 Table 4.3: Result for surface roughness of uncoated carbide tool with difference feed rate when machining cast iron in dry condition.

Control Parameter					Result			
No. of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (µm)
1	3026	120	1.25	20	0.729	0.827	0.831	0.796
2	3026	165	1.25	20	0.923	0.91	1.254	1.029
3	3026	375	1.25	20	1.351	1.45	1.541	1.447
4	3026	520	1.25	20	1.737	1.798	1.854	1.796
5	3026	720	1.25	20	2.454	2.312	2.53	2.432

B.4 Table 4.4: Result for surface roughness of coated carbide tool with difference feed rate when machining cast iron in dry condition

Control Parameter					Result			
No.of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (µm)
1	3026	120	1.25	20	0.832	0.789	0.721	0.781
2	3026	165	1.25	20	0.985	0.874	0.901	0.920
3	3026	375	1.25	20	1.167	1.103	1.064	1.111
4	3026	520	1.25	20	1.264	1.064	1.081	1.136
5	3026	720	1.25	20	1.250	1.240	1.200	1.230

B.5 Table 4.5: Result for surface roughness of uncoated carbide tool with difference Depth of Cut when machining cast iron in dry condition.

Control Parameter					Result			
No.of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (µm)
1	3026	120	0.75	20	0.729	0.827	0.831	0.796
2	3026	120	1.25	20	0.877	0.785	1.105	0.922
3	3026	120	1.75	20	0.803	1.375	1.361	1.180
4	3026	120	2.50	20	1.367	1.534	1.065	1.322
5	3026	120	3.50	20	1.674	2.011	1.827	1.837

B.6 Table 4.6: Result for surface roughness of uncoated carbide tool with difference Radial Depth of Cut when machining cast iron in dry condition.

Control Parameter					Result			
No of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (µm)
1	3026	120	0.75	20	0.364	0.595	0.456	0.472
2	3026	120	1.25	20	0.914	0.793	0.966	0.891
3	3026	120	1.75	20	1.162	1.236	1.297	1.156
4	3026	120	2.50	20	1.21	1.118	1.139	1.232
5	3026	120	3.50	20	1.414	1.342	1.489	1.415

B.7 Table 4.7: Result for surface roughness of uncoated carbide tool with difference Radial Depth of Cut when machining cast iron in dry condition.

Control Parameter					Result			
No. of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (μm)
1	3026	120	0.75	5	0.878	0.851	0.667	0.721
2	3026	120	0.75	10	0.730	2.250	2.230	0.814
3	3026	120	0.75	15	0.877	0.785	1.105	0.922
4	3026	120	0.75	20	1.088	1.033	0.982	1.034

B.8 Table 4.8: Result for surface roughness of coated carbide tool with difference Radial Depth of Cut when machining cast iron in dry condition.

Control Parameter					Result			
No of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (μm)
1	3026	120	0.75	5	0.500	0.621	0.514	0.545
2	3026	120	0.75	10	0.752	0.735	0.763	0.750
3	3026	120	0.75	15	0.826	0.881	0.756	0.821
4	3026	120	0.75	20	0.953	0.889	0.925	0.922

B.9 Table 4.9: Result for surface roughness of uncoated carbide tool with difference Machining Time when machining cast iron in dry condition

Control Parameter						Result			
No. of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Machining Time (s)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (µm)
1	3026	120	0.75	20	60.0	1.037	0.992	1.123	1.051
2	3026	120	0.75	20	120.0	1.316	1.32	1.328	1.321
3	3026	120	0.75	20	180.0	1.345	1.289	1.398	1.344

B.10 Table 4.10: Result for surface roughness of coated carbide tool with difference Machining Time when machining cast iron in dry condition.

Control Parameter						Result			
No of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Machining Time (s)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (µm)
1	3026	120	0.75	20	60.0	0.698	0.793	0.761	0.730
2	3026	120	0.75	20	120.0	0.911	0.705	0.652	0.756
3	3026	120	0.75	20	180.0	0.767	0.793	0.783	0.781

B.11 Table 4.11: Result for surface roughness of coated carbide tool with difference Machining Length when machining cast iron in dry condition.

Control Parameter						Result			
No of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Machining Length (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (μm)
1	3026	120	0.75	20	150	0.364	0.595	0.456	0.472
2	3026	120	0.75	20	300	0.391	0.489	0.391	0.424
3	3026	120	0.75	20	450	0.381	0.456	0.479	0.439
4	3026	120	0.75	20	600	0.398	0.468	0.431	0.433
5	3026	120	0.75	20	750	0.478	0.411	0.431	0.440

B.12 Table 4.12: Result for surface roughness of uncoated carbide tool with difference Machining Length when machining cast iron in dry condition.

Control Parameter						Result			
No. of Exp	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Machining Length (mm)	Surface Roughness 1st	Surface Roughness 2nd	Surface Roughness 3rd	Average Surface Roughness (μm)
1	3026	120	0.75	20	150	0.987	0.879	1.051	0.972
2	3026	120	0.75	20	300	0.841	0.825	1.016	0.894
3	3026	120	0.75	20	450	0.978	0.881	0.896	0.918
4	3026	120	0.75	20	600	0.875	1.052	1.023	0.983
5	3026	120	0.75	20	750	0.769	0.876	1.253	0.966

B.13 Table 4.13: Result for power of coated and uncoated carbide tool with difference spindle speed when machining cast iron in dry condition.

Control Parameter					**Result**	
					Uncoated	Coated
No of Expr	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	WP (kWh)	WP (kWh)
1	1000	165	1.25	20	2.24	3.85
2	1487	165	1.25	20	2.50	3.88
3	2015	165	1.25	20	2.86	3.91
4	2495	165	1.25	20	2.90	4.16
5	3026	165	1.25	20	3.15	4.37

B.14 Table 4.14: Graph of average power vs cutting parameter for coated and uncoated carbide tools

Control Parameter					**Result**	
					Uncoated	Coated
No of Expr	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	WP (kWh)	WP (kWh)
1	3026	120	1.25	20	4.03	4.40
2	3026	165	1.25	20	3.20	3.93
3	3026	375	1.25	20	1.84	1.84
4	3026	520	1.25	20	1.46	1.46
5	3026	720	1.25	20	0.25	0.97

B.15 Table 4.15: Result for power of coated and uncoated carbide tool with difference depth of cut when machining cast iron in dry condition.

Control Parameter					Result	
					Uncoated	Coated
No of Expr	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	WP (kWh)	WP (kWh)
1	3026	120	0.75	20	3.59	1.52
2	3026	120	1.25	20	4.03	1.80
3	3026	120	1.75	20	4.55	1.88
4	3026	120	2.50	20	5.00	2.09
5	3026	120	3.50	20	5.33	2.73

B.16 Table 4.16: Result for power of coated and uncoated carbide tool with difference Radial depth of cut when machining cast iron in dry condition.

Control Parameter					Result	
					Uncoated	Coated
No of Expr	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	WP (kWh)	WP (kWh)
1	3026	120	0.75	5	3.21	1.47
2	3026	120	0.75	10	3.36	1.50
3	3026	120	0.75	15	3.43	1.49
4	3026	120	0.75	20	3.59	1.52

B.16 Table 4.16: Result for power of coated and uncoated carbide tool with difference Machining length when machining cast iron in dry condition.

Control Parameter						Result	
						Uncoated	Coated
No of Expr	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Machining Length (mm)	WP (kWh)	WP (kWh)
1	3026	120	0.75	20	150	3.59	1.52
2	3026	120	0.75	20	300	7.16	3.04
3	3026	120	0.75	20	450	10.79	4.55
4	3026	120	0.75	20	600	14.37	6.09
5	3026	120	0.75	20	750	17.92	7.59

Table 4.17: Result for power of coated and uncoated carbide tool with difference Machining Time when machining cast iron in dry condition.

Control Parameter						Result	
						Uncoated	Coated
No of Expr	Cutting Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Radial Depth Of Cut (mm)	Machining Time (s)	WP (kWh)	WP (kWh)
1	3026	120	0.75	20	60.0	2.38	2.21
2	3026	120	0.75	20	120.0	3.24	2.90
3	3026	120	0.75	20	180.0	5.63	5.11

APPENDIX C
MACHINE AND EQUIPMENT USED IN EXPERIMENT

C.1 Horizontal Band Saw Machine

C.2 Cutting Material process by Using Horizontal Bans Saw Machine

C.3 Grinding Machine

C.4 Clamping Meter

C.5 Clamp Sensor

C.6 Result of Uncoated Tool

C.7 Result of Coated Tool