EFFECT OF DRY MACHINING ON TOOL WEAR

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This thesis is submitted as a partial fulfillment of the requirements for the award of the bachelor of mechanical engineering with manufacturing engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

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BORANG PENGESAHAN STATUS TESIS

JUDUL: EFFECT OF DRY MACHINING ON TOOL WEAR

SESI PENGAJIAN: 2011/2012

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FACULTY OF MECHANICAL ENGINEERING

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ID Number: ME08032

Date:

IN THE NAME OF ALLAH,

THE MOST BENEFICENT, THE MOST MERCIFUL

A special dedication of This Grateful Feeling to My..

Beloved parents, En.Zubir bin Daud and Pn. Laila binti Mohd Zain for giving me full of moral and financial support. It is very meaningful to me in order to finish up my degree's study. Not forgetting also to all my loving siblings, and also to my beloved one. Last but not least to all my colleagues and my lovely friends.

Thanks for all the support, wishes and love.

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ABSTRACT

This thesis presents the wear of coated carbide insert in machining carbon steel AISI 1065. Machineability of AISI 1065 is considered good with high strength, high resistance to breakage and high modulus of elasticity. This has increased the tool wear of the coated carbide when it is used to machining of AISI 1065. The main objective of this project is to examine the progress of tool wear, identify the interaction between the different parameters and to find out the optimal parameter that can be used in dry machining. In this project, 3^3 full factorial design of experiments (DOE) was employed in STATISTICA software to plan and perform the experiment systematically so that any possible experimental error would be minimized. Machining variables considered are cutting length, cutting speed and feed rate. The variables for there levels were 90, 120 and 150 rev/min for cutting speed, 0.13, 0.18, 0.22 mm/rev for the feed rate and 0.8, 1.0, and 1.2 mm for depth of cut respectively. Machining AISI 1065 was carried out by using the conventional lathe machine. The work piece is been turning for 7 rounds for each turning process. After 7 rounds of turning process, wear of the coated carbide insert was investigated and measured by using Microscope MarVision MM320 and Quadra check 300. Experimental data was analyzed in STATISTICA. Analysis of variance (ANOVA) is done to identify the most influencing parameters in this research. From the ANOVA analysis, the cutting speed and the feed rate are the most significant parameter that influencing tool wear. Depth of cut effect can be negligible. The minimum tool wears is at the lowest cutting speed that is 90rev/min and at lowest feed rate 0.13mm/rev.

ABSTRAK

Tesis ini menyajikan kehausan mata alat pemotong diselaputi karbide dalam memesinkan besi karbon AISI 1065. Kebolehmesinan besi AISI 1065 dimesinkan adalah dengan kekuatan yang tinggi, keupayaan menahan dari patah, dan nilai modulus kekenyalan yang tinggi . Ini menyebabkan alat pemotong diselaputi karbide akan cepat haus. Objektif utama projek ini ialah untuk mengkaji kemajuan kehausan alat mata, mengenalpasti interaksi antara parameter yang berlainan dan untuk mengetahui parameter yang optimum yang boleh digunakan dalam pemesinan kering. Dalam projek ini, rekaan eksperimen pemfaktoran penuh 3^3 dijanakan dalam perisian STATISTICA untuk mengatur dan menjalankan eksperimen ini secara sistematik untuk mengurangkan apa-apa ralat eksperimen yang mungkin berlaku. Parameter yang dipertimbangkan ialah kelajuan pemotongan, kadar kelajuan pemotongan dan kedalaman pemotongan. Tiga tahap parameter yang digunakan ialah 90, 120 dan 150 rev/min untuk kelajuan pemotongan, 0.13, 0.18 dan 0.22 mm/rev untuk kadar kelajuan bahan dipotong dan 0.8, 1.0 dan 1.2 untuk kedalaman pemotongan. Proses memesinkan besi AISI 1065 dijalankan dengan menggunakan mesin larik konvensional. Bahan kajian dilarikkan untuk 7 pusingan untuk setiap proses larikan. Selepas 7 proses larikan, kehausan alat pemotong disepaluti karbide dikaji dan diukur menggunakan mikroskop MarVision MM320 dan Quadra Chek 300. Data eksperimen dianalisis menggunakan STATISTICA. Analisis varians (ANOVA) dilakukan untuk mengenalpasti parameter yang paling mempengaruhi kehausan alat pemotong. Daripada analisis ANOVA, kelajuan pemotongan dan kadar kelajuan pemotongan adalah parameter yang paling penting yang mempengaruhi kehausan alat pemotong. Kesan kedalaman pemotongan boleh diabaikan. Kehausan mata pemotong paling minimum adalah pada kelajuan pemotongan 90rev/min dan kadar kelajuan pemotongan 0.13mm/rev.

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°C	Degree Celsius
γ	Gamma
R^2	Coefficient of determination

LIST OF ABREVIATIONS

DOE	Design of Experiments
AISI	American Iron and Steel Institute
ANOVA	Analysis of variance
HV	Hardness value
RPM	Revolutions per minute
FCC	Face centred cubic
BCT	Body central tetragonal
CVD	Chemical vapour deposition
SS	Sum of squares
CS	Cutting speed

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

During machining process, friction between work piece and grain cause high temperature on cutting tool. The effect of this generated heat that will sooner decrease the tool life, increase surface roughness and decrease the dimensional sensitivities of work material. This case is more important when machining of difficult-to-cut materials, when more heat would be observed.

The application of cutting fluid or coolant is an alternative that has been used widespread in all machining process. Cutting fluid is used to reduce friction and wear (improving tool life and surface finish), to reduce cutting force and energy consumption, to cool the cutting zone, to wash away chips and to protect machined surfaces from environmental corrosion.

However, because of their damaging influences on the environment, their applications have been limited in machining process. Cutting fluid can be expensive and seriously degrade quality of environment. Consequently, many governments recommend the manufacturers to reduce the volume and the toxicity of their cutting fluids. It is potentially cause health problem to the operator. Besides, cutting fluids requires proper recycling and disposal, thus adding to the cost of the machining operation.

For these reasons dry machining has become an increasingly important approach. In dry machining, no coolant or lubricant is used. The implementation of dry machining will bring down the manufacturing cost.

In this project, the material used is high carbon steel that have undergo heat treatment process to make it stronger and harden so that the tool wear can be analyzed. The material will then be tested for its hardness number.

Three different parameters are used in this project that is speed of the machine, depth of cut and also the feed rate. Every parameter is conducted in three different conditions that are low, medium and high values. The STATISTICA software will generate the table of runs to find which parameters values will be used first before go through the turning process by using the Conventional Lathe machine. Then, the tool will be scanned to its wear after specific number of turning processes.

In this study, we observed the tool wear only focus on flank wear because the flank wear can be more easily observed and measured than other types of wear.

1.2 PROBLEM STATEMENT

1.2.1 Problem

The advantages of cutting fluid have been questioned lately due negative effects. Cutting fluid can cause adverse health effects such as skin and respiratory disease. Cutting fluids also increase amount of machining cost in a company. Company have to spend more money in order to dispose the cutting fluids. Dry machining seems to be more economical but can cause tool wear problems.

1.2.2 Solution of the problem

Some of the alternatives to minimize the tool wear problems without decrease the surface quality are chosing the right parameters. Different parameters such as depth of cut, speed of the machine and the feed rate is investigated in dry machining experiment in order to find out the optimal parameters values that suitable with dry machining. Design of the experiment (DOE) is generate using STATISTICA software to control the parameters is important in this study as it applied to get the result to prove that the method in Design of Experiment (DOE) can provide accurate result. Study of tool wear is still need to be done in order to reduce the tool wear of coated carbide insert.

1.3 PROJECT OBJECTIVE

The objectives of this study are to:

i. To identify the effect of tool wear with dry machining with different parameters for hardened carbon steel.
ii. To analyze the relationship between parameters that leading to tool wear.
iii. To recommend the best machine parameter that contributes to minimum tool wear.

1.4 SCOPE OF PROJECT

i. Materials will be tested to find the composition and the result is then compared with the material composition chart to know the type of the material and the composition.
ii. Heat treatment will be conducted to harden the material and the hardness number is calculated after doing the hardness test.
iii. Experiment is run for different parameters that is cutting speed V_c = (90, 120, 150 m/min), depth of cut (0.8, 1.0, 1.2mm) and feed rate, f (0.13, 0.18, 0.22rev/mm) by using Conventional Lathe Machine.
iv. Tool wear is analyzed by using metallurgical microscope integrated with Image Analyzer and the length of the wear is measured.
v. Analysis of variance (ANOVA) to find most critical factor.

1.5 SUMMARY

Chapter 1 generally discussed about project background, problem statement, objectives and scopes of the project in order to complete the investigation of wear of coated carbide insert in dry machining AISI 1065. This chapter is a fundamental for this project and as a guideline to complete this research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, it will discuss about the research that have been done about the related issues in this project. The definition of each term will be included in this chapter. Dry machining, harden carbon steel are among the interested terms in the project. The source of the literature review is from journals, articles and books. Literature review is done to provide information about previous research and the relevant that can help to smoothly run this project.

2.2 PLAIN CARBON STEEL

Carbon steel is by far the most widely used kind of steel. The properties of carbon steel depend primarily on the amount of carbon it contains. Most carbon steel has a carbon content of less than 1%. Carbon steel is made into a wide range of products, including structural beams, car bodies, kitchen appliances and cans. It is good to precise that plain carbon steel is a type of steel having a maximum carbon content of 1.5 % along with the small percentages of silica, sulphur, phosphorus and manganese (Kalpakjian, 2001)

Steel is an alloy of iron and carbon, where other elements are present in quantities too small to affect the properties. The other elements allowed in plain carbon steel are manganese and silicon. Steel with low carbon content has the same properties as iron, soft but easily formed. As carbon content rises, the metal becomes harder and stronger but less ductile and more difficult to weld. Higher carbon contents lower steel melting point and its temperature resistance in general (Smith and Hashemi, 2006).

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Generally, with an increase in the carbon content from 0.01% to 1.5% in the alloy, its strength and hardness increases but still such an increase beyond 1.5% causes appreciable reduction in the ductility and malleability of the steel. They are classified by three major categories, which are low carbon steel, medium carbon steel, high carbon steel and as their names suggests all these types of plain carbon steel differs in the amount of carbon they contain (Armstead, 2007)

i. Low carbon steel

Containing carbon up to 0.25% responds to heat treatment as improvement in the ductility is concerned but has no effect in respect of its strength properties

ii. Medium carbon steel

Having carbon content ranging from 0.25 to 0.70% improves in machinability by heat treatment. It must also be noted that this steel is especially adaptable for machining or forging and where surface hardness is desirable.

iii. High carbon steel

High carbon steel contains carbon up t0 0.7% to 1.05%. In heat-treated condition it is very hard and it will withstand high shear and wear and thus will subject to little deformation. There are also other properties of plain carbon steel that need to be considered and these properties are being illustrated as shown in Table 2.1 shown:

Table 2.1: Properties of plain carbon steel

Material	Density $(10^3 kgm^{-3})$	Thermal conductivity J $m^{-1}K^{-1}s^{-1}$	Thermal expansion $10^{-6}K^{-1}$	Young's Modulus MNm^{-2}	Tensile Strength MNm^{-2}	% elongation
0.2% C steel	7.86	50	11.7	210	350	30
0.4% C steel	7.85	48	11.3	210	600	20
0.8% C steel	7.84	46	10.8	210	800	8

Source: Raghavan (2002)

2.3 HEAT TREATMENT

2.3.1 Introduction

Heat treatment is defined as a physical process which entails the controlled heating and cooling materials, such as metal or alloys to obtain desired properties. Heat treating is an energy intensive process that is carried out in different furnace such as electric and gas. Shortening heat treatment cycles can provide great environment and financial benefits through energy saving. Many texture detail furnace equipment and its design but little to no literature can be found in furnace temperature method (Saleh, 2001)

Heat treatment involves the application of heat, to a material to obtain desired material properties (e.g. mechanical, corrosion etc). During heat treatment process, the material usually undergoes phase microstructure and crystallographic changes (Rajan et al., 1989). The purpose of heat treating carbon steel is to change the mechanical properties of steel, usually ductility, hardness, yield strength tensile and impact resistance. The electrical, corrosion and thermal conductivity are also slightly altered during heat treatment process (Mamoru et al., 1990)

Hardenability is one measure of the heat treatability of steel. The typical heat treatment begins with an austenitizing treatment followed by quenching to form martensite. The martensite is then tempered. This softens the material somewhat but increases the toughness considerably. Ideally, the quench would produce a 100% martensitic structure so that the tempering treatment will produce a part with uniform hardness. In plain carbon steels, however only the first 1/8-3/8 inches near the surface is quenched rapidly enough to form 100% martensite. The deeper sections contain progressively softer microstructures. A more severe quench might produce 100% martensite to a greater depth but it can also lead to warping and cracking, especially inlarge parts or ones in which the thickness varies abruptly (Mamoru et al., 1990).

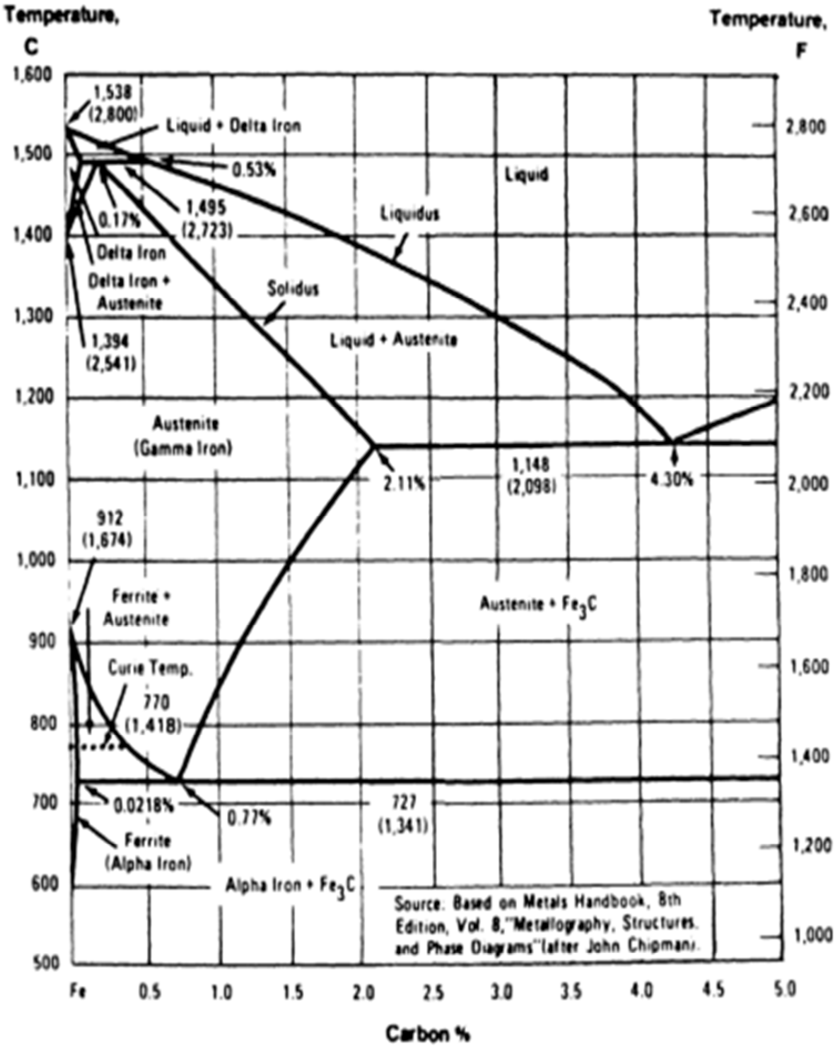

Figure 2.1: Fe-Fe_3C equilibrium phase diagram

Source: Mike (2004)

When carbon steel is heated above its upper critical (about 760°C), the iron crystal structure will change to face centered cubic (FCC), and the carbon atoms will migrate into the central position formerly occupied by an iron atom. This form of red-hot steel is called austentite (γ iron). After quenching in water, carbon atoms are trapped and the result is very hard, brittle steel. This steel crystal structure is now a body centered tetragonal (BCT) form called martensite. By rapidly cooled by immerse the red hot steel in water, and there is insufficient time for the martensite to break down to iron and carbon. If cooled slowly, the martensite reverts to iron and carbon again and the steel remains soft. Martensite looks needle-like under microscope due to its fine lamellar structure (Mike, 2004).

2.3.2 Heat Treatment Process

All the different heat treatment processes consists the following three processes:

1) Heating the material

2) Soaking time

3) Cooling, usually to room temperature

However, the temperature and time for the various processes is dependent on the material mechanism controlling the wanted effect. For example, if the driving mechanism is diffusion the time must be long enough to allow any necessary transformation reaction. During heating and cooling, there is existing temperature gradients between the outside and interior portion of the material; their magnitudes depend on the size and geometry of the work piece. If the rate of temperature change in the surrounding is too high, large temperature gradients may develop in the component. This creates internal stresses that may lead to the plastic deformations and even to cracking. Annealing is a treatment that consists of heating and holding suitable temperature followed by cooling at suitable rate. Steels may be annealed to smooth the progress of cold working or machining, to improve mechanical or electrical properties (Smith and Hashemi, 2006).

Annealing is typically carried out to relieve stresses, increase softness, ductility, and toughness, to produce a specific microstructure and negate the effect of cold work. In annealing temperature is roughly one-third of the melting temperature for a pure metal. For alloys, the temperature can be as high as one-seventh of the melting temperature. Since atomic diffusion processes normally are involved in annealing, the temperature and time are important parameters. The mechanism active during annealing is recovery and recrystallisation. Grain growth is generally not allowed to occur. Common selective method of hardening processes is (Smith and Hashemi, 2006):

- Flame Hardening
- Induction Hardening
- Laser Beam Hardening
- Electron Beam Hardening

The hardness values of the heat- treated specimens are generally higher than that of unheated-treated steel. In this case, the ability of the material to resist plastic deformation under indentation was used to evaluate hardness. The highest value of hardness is obtained on water quenched steel. Water should be used if plain carbon steel is to have a high value of hardness. (Kumar, 1995)

2.3.2 Quenching process

This is the process of rapid cooling of materials to room temperature to preserve the solute in solution. The cooling rate needs to be fast enough to prevent solid – state diffusion and precipitation of the phase. The rapid quenching creates a saturated solution and allows for increased hardness and improved mechanical properties of the material. In addition, studies have shown that the highest degrees of corrosion resistance have been obtained through the maximum rates of quenching (Smith and Hashemi, 2006).

If the steel is cooled quickly (quenching) by immersing it in oil or water, the carbon atoms are trapped and the result is very hard, brittle steel. This steel crystal structure is now a body centered tetragonal (BCT) form called martensite. Quenching is the act of rapidly cooling the hot steel to harden the steel. Some of the medium used are (Smith and Hashemi, 2006):

1) Water: As the water contacts and boils, a great amount of heat is removed from the steel. Water is a good rapid quenching medium but corrosive with steel.

2) Oil: Oil usually use when slower cooling rate is desired and can reduce cracking.

3) Salt Water: Salt water is a more rapid quench medium than plain water but more corrosive than plain water.

4) Polymer quench: Polymer quenches produce less corrosion than water and less of a fire hazard than oil.

5) Cryogenic Quench: Cryogenics or deep freezing is done to make sure there is no retained Austenite during quenching.

Increase solution treatment temperature was found in improved soluble precipitates in the alloy, and the heat extraction capacity of the quenching medium also contributed to the formation of fine precipitates. Water among the quenching media proved to have the highest cooling rate, followed by sheanut oil. Improvements in properties may be correlated with a more refined metallurgical structure (Saleh, 2001).

2.4 VICKERS HARDNESS TEST

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a test force of between 1gf and 100kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surfaces of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation (Mikell, 2010)

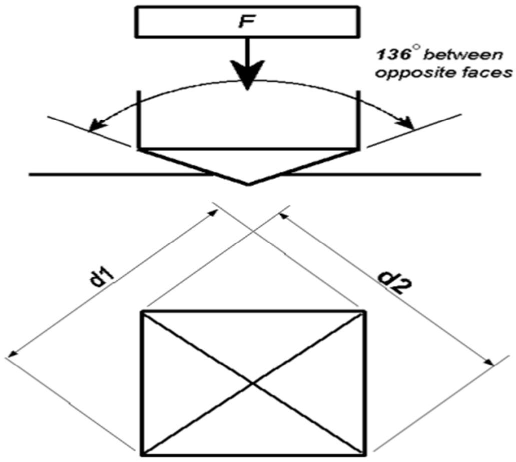

Figure 2.2: Vickers Pyramid Hardness Indentation

Source: Mikell (2010)

$$HV = \frac{2F\sin\frac{136°}{2}}{d^2} \quad \text{Eq. (2.1)}$$

$$HV = 1.854\ \frac{F}{d^2}\ \text{Approximately} \quad \text{Eq. (2.2)}$$

When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula. Modern digital Vickers hardness testers perform this calculation automatically and report the appropriate hardness result. The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kgf test force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods (Mikell, 2010).

The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. The Vickers method is capable of testing the softest and hardest of materials, under varying loads. With modern advances in technology, PCs and software development, it is now possible to offer automatic indentation measurement. This has the benefit of eliminating any operator influence over the result, reducing R&R (repeatability and reproducibility) and uncertainty budgets. Automatic test surface focusing, motorised XY tables and automatic effective case depth determination are common place in advanced laboratories around the world who require the latest technology offering fast, reliable and traceable testing (Mikell, 2010).

2.5 DRY MACHINING

Dry machining is a machining process without coolant or cutting fluids, and it has become more popular as a finishing process. To eliminate or reduce the use of cutting fluids has therefore become a recent technology trend. The cutting fluids applied in machining processes basically have three characteristics (Baraide, 1996). These are:

a. Cooling effect

b. Lubrication effect

c. Taking away formed chip from cutting zone

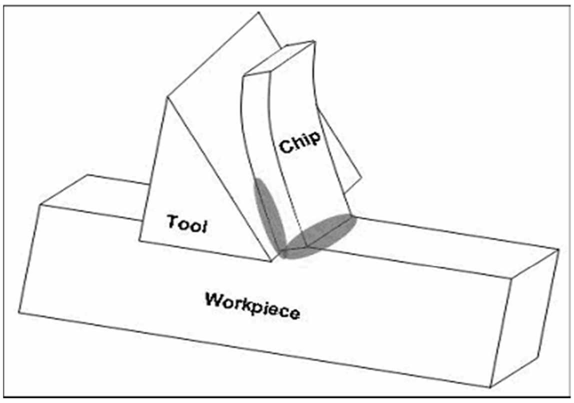

Figure 2.3: Region of heat generation in machining

Cutting fluids, usually in the form of liquid are applied to the chip formation zone in order to improve the cutting conditions. In machining, coolants and lubricants improve machinability, increase productivity by reducing the tool wear, better surface finish and extend tool life. Jan and Krzyztof (1995) had been concluded that the application of cutting fluids in machining processes would make shaping process easier.

Despite these benefits, the use of cutting fluids also brings about some disadvantages. Using cutting fluids seriously degrades the environment quality and increases the cost of machining. When inappropriately handled, cutting fluids may damage soil and water resources, causing serious loss to the environment. Therefore, the handling and disposal of cutting fluids must obey rigid rules of environmental protection. On the shop floor, the machine operation may be affected by the adverse effects of cutting fluids, such as by skin and breathing problem (Isakov, 2003).

For the companies, the cost related to cutting fluids represents a large amount of the total machining costs. Several research workers, state that the costs related to the cutting fluids are frequently higher than those related to cutting tools. Consequently, elimination on the use of cutting fluids, if possible, can be significant economic incentive. Considering the high cost associated with the use of cutting fluids and projected escalating costs when the stricter environmental laws are enforced, the choice seems obvious. Because of them some alternatives has been sought to minimize or even avoid the use of cutting fluids in machining operations (Baradie, 1996)

Completely dry machining is acceptable only when part quality, tool life, and other process quality attributes are assured. Thus, it is especially crucial to select the machining parameters to obtain the desired surface finish of machined component (Jan and Krzyztof,1995)

The application of cutting fluids is another alternative to obtain higher material removal rates. Cutting fluids have been used widespread in all machining processes. However, because of their damaging influences on the environment, their applications have been limited in machining processes (Baradie,1996) New approaches for elimination of cutting fluids application in machining processes have been examined and dry machining was presented as an important solution (Sreejith and Ngoi, 2000).

The development of new cutting tool materials also helped dry machining method to be a positive solution for cutting tool materials also helped dry machining method to be a positive solution for cutting fluids application. However, the usage of cutting fluids has been increased due to high production levels in the world. According to 1998 values, approximately 2.3x109 litre cutting fluids have been used in the machining operations and its cost value was around $ 2.75x109 North America had a big ratio, Europe continent was in the third order after Asia continent (Baradie, 1996)

2.6 LATHE MACHINE

One of the most important machine tools in the metalworking industry is the lathe machine. Turning is one of the most common metal cutting operations. In turning, a work piece is rotated about its axis as single-point cutting tools are fed into it, shearing away unwanted material and creating the desired part. Turning can occur on both external and internal surfaces to produce an axially-symmetrical contoured part.

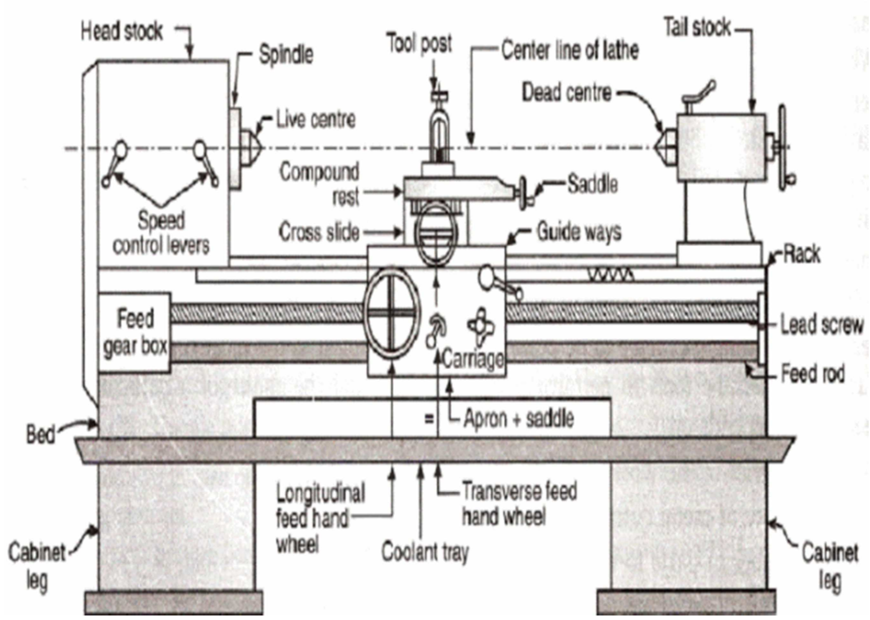

Figure 2.4: Lathe Machine

Source: Mikell (2010)

The work may be held on one or by both its ends. Holding the work by one end involves gripping the work in one of several types of chucks or collets. Chucks are mounted on the spindle nose of the lathe, while collets usually seat in the spindle. The spindle is mounted in the lathe’s headstock, which contains the motor and gear train that makes the rotation possible (Mikell, 2010)

Directly across from the headstock on the lathe is the tailstock. The tailstock can hold the work by either a live or dead centre. Work that is held at both ends is said to be between centres. Additionally, longer work piece may have a “steady rest” mounted between the headstock and tailstock to support the work. Typically work pieces are cylindrical, but square and odd shapes stock can also be turned using special chucks or fixtures (Yeo, 1995).

Lathe cutting tools brought to the work may move in one or more directions. Tool movement on the engine lathe is accomplished using a combination of the lathe’s carriage, cross slide and compound rest. The carriage travels along the machine’s bed ways, parallel to the work piece axis. This axis is known as the Z-axis. Motion perpendicular to the work is called the X-axis. On an engine lathe this motion is provided by the cross slide mounted on the carriage (Armstead et al., 1987)

External turning can be broken down into a number of basic operations. “Straight turning” reduces the work to a specified diameter equally along the work’s axis. “Taper turning” produces a taper along the axis of the work piece. Tapers are produced by either offsetting the tailstock from centreline or by using a “tapper attachment”. “Contour turning” uses a single-point cutting tool to reproduce a surface contour from a template. “Forming” uses a cutting tool ground with the form or geometry of the desires shape. Other external lathe operations include “chamfering” top remove sharp edges, “grooving” to produce recesses and shoulders, “facing” to finish the ends of a work piece, “parting” to cut off finished pieces from the stock, and “thread chasing” with tools to produce the desired thread form(Yeo, 1995).

The most common method of internal turning on the lathe is to present the rotating end of a work piece to the point of a non-rotating drill bit mounted in the tailstock. Roughly drilled holes are finished to exact size by using a reamer which also mounts in the tailstock. Large diameter holes are made by boring. A boring bar with a cutting tool attached is moved along the work’s axis as in surface cutting, but inside a previously drilled hole. Internal threads are obtained by using tapping tools mounted in the tailstock (Yeo, 1995).

Three keys parameters determine productivity and part quality are the cutting speed, the feed rate and the depth of cut. The cutting speed is the speed of the work as it rotates past the cutting tool. The feed rate is the rate at which the tool advances into the work. The depth of cut is the amount of material removed as the work revolves on its axis. Other factors include the machinability of the stock, the type and the geometry of the cutting tool, the angle of the tool to the work, and the overall condition and power of the lathe itself (Yeo, 1995).

2.6.1 Turning high carbon steel

Cutting forces and tool wear are higher when turning high-carbon steels than they are when turning medium carbon steels, because of higher carbon content. Therefore, lower cutting speeds are necessary to minimize tool wear (Isakov, 2003).

2.7 COATED CARBIDE INSERT CUTTING TOOLS

Carbide insert are widely used in metal cutting industry for the cutting of various hard materials. During metal cutting process, tools have to resist extreme heat, high pressure, abrasion, thermal shock and mechanical shock. Chemical stability and hardness of chemical vapour deposition (CVD) coated carbide tools are much better than that of the uncoated carbide cutting tool. Hard coatings are applied in most of the carbide tools since they offer proven benefits in terms of tool life and cutting performance (Mikell, 2010)

During metal cutting process, tools have to resist extreme heat, high pressure, abrasion, thermal shock and mechanical shock. Hard coatings are applied in most of the carbide tools since they offer proven benefits in terms of tool life and cutting performance. Chemical stability and hardness of chemical vapour deposition (CVD) coated carbide tools are much better than that of the uncoated carbide substrate. However, the toughness of CVD coated carbide tools is not as good as that of the uncoated carbide substrate. (Mikell, 2010)

Besides, coating is also used on cutting tools to improve lubrication at the tool chip and workpiece interfaces and also to reduce friction and will reduce the temperature at the cutting edge. During machining, coated carbide tools ensure higher wear resistance, lower heat and lower cutting force. So it wills enable them to perform better at higher cutting conditions than uncoated cutting tools (Mari and Gonseth, 1993)

Table 2.2: Tool life, surface roughness and cutting force when machining cast iron T150M coated carbide tool in dry condition.

Trial no.	Dry Condition	Feed rate, *f* (mm/rev)	Depth of cut (mm)	Tool life (min)	Surface roughness Ra (μm)	Cutting force Fc (N)
1	Without air	0.4	0.6	8.01	6.320	562
2	Without air	0.3	0.8	6.71	3.175	293
3	Without air	0.15	1.0	8.98	1.777	262
4	Normal air	0.4	0.6	10.45	6.202	132
5	Normal air	0.3	0.8	11.91	3.622	597
6	Normal air	0.15	1.0	14.27	1.827	296

Source: Eghawail et al. (2010)

Cutting temperature is an important factor in the machining operations as it strongly influences the cutting forces, tool life and the work piece surface integrity. Higher cutting temperature decrease the yield strength of the work piece material, making it more ductile. However, increased work piece surface temperatures cause problems like white layer formation. Most importantly, the tool life is affected by increasing the cutting temperature. Lower temperature, make tool life longer (Eghawail et al., 2010)

Carbides are the most prevalent tool materials, they are tough and they can be used for machining using high feed rate speed, and for difficult intermittent machining. Coated carbides consist of a hard carbide base and coating, which increases the thermo chemical stability (carbides, nitrides, oxides and their combinations). As a result we get high-quality materials for a high rate of material removal and intermittent machining. (Mari and Gonseth, 1993)

2.8 TOOL WEAR

Tool wear is the rate at which the cutting edge of a tool wears away during machining. It includes (Sigl and Fischmeister, 1998)

1. Flank wear – Flank wear is tool wear resulting the gradual wearing away of the cutting edge. Flank wear mostly caused by abrasion, and it is the desired form of tool wear.

2. Crater wear- Tool wear that creates a concave depression in the face of the cutting tool above the cutting edge.

Flank wear probably occur by both abrasive and adhesive wear mechanisms with abrasive wear being the major source of material removal since the temperatures at tool flank lower than that on the rake face. Abrasive is mainly caused by the hard, martensitic structure of the hard work material. The relative motion between the newly cut surface and the flank of the cutting tool in the presence of hard particles results in the development a flat of the flank faces of the cutting tool. Tool material is removed by ploughing, scoring, micro-cutting, or grooving with the said hard particles. A rubbing action takes place between tool flank and hard martensite structure which removes material in the flank side (Suh, 1980)

As the cutting speed and feed rate increase, the temperature in the chip formation region also tends to rise. The cutting tools in conventional machining particularly in continuous chip formation processes like turning, generally fail by gradual wear by abrasion, adhesion, diffusion, chemical erosion, galvanic action etc. Depending upon the tool-work materials and machining conditions. Tool wear initially starts with a relatively faster rate due to what is called break-in wear caused by attrition and micro chipping at the sharp cutting edges (Suh, 1980).

Usui (1998) observed that wear pattern depend on the CBN tools used, work piece material composition, and cutting conditions. They also concluded that generally, adhesion, abrasion and diffusion are considered to be main tool wear mechanisms. A few basics mechanisms dominate cutting tool wear are:

1) Diffusion wear affected by chemical loading on the tool and cutting material.
2) Oxidation wear causes gaps to occur in coated film and results in a loss of the coating at elevated temperature
3) Fatigue wear is a thermo-mechanical effect and leads to the breakdown of the edges of the cutting tool
4) Adhesive wear occurs at low machining temperatures on the chip face of the tool and leads to the formation of a built up edge, and the continual breakdown of the built up edge and the tool edge itself
5) Abrasive wear affected by hardness of the work material and is controlled by content of the cutting material.

They also observed that the temperature rise during cutting could reduce the strength of the tool and the wear resistance of the tool. Though chip control geometry may play a role in the growth of flank wear, its primary affect on tool wear is more likely related to crater wear. On the other hand, while edge preparation probably plays a role in the growth of crater wear, intuition, anecdotal evidence and limited published data support the notion that edge preparation is closely linked to flank wear growth (Jiri and Jaroslav, 2009)

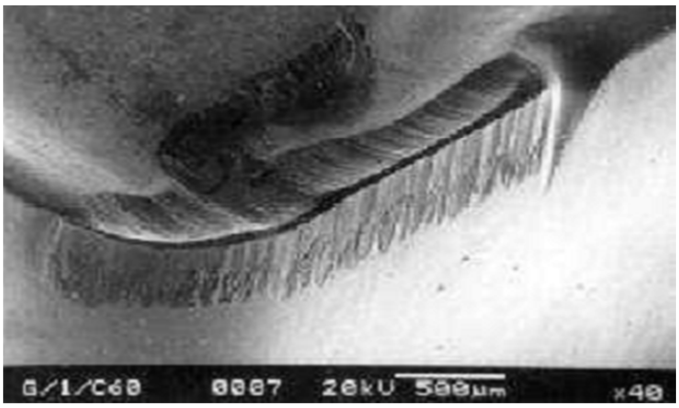

Figure 2.5: Flank wear carbide insert tool of turning C-60 steel

Source: Jiri and Jaroslav(2009)

One of the most important phenomena occurring during the machining process is the heat generation in the cutting zone. Komanduri (2001) agree that most of the energy applied to the cutting process is converted into heat in the main zone of plastic deformation, the shearing plane, where the work piece material turns itself into chip and in the secondary zone of plastic deformation, where chip slides on the rake face. Finally, some heat also arises on the tertiary zone, where the tool relief face slides on the newly machined surface. This last source is, however not considered in most cases, either for simplicity, or because the heat generated is very small when using sharp cutting edges. The heat generated in those zones is distributed among the tool, the work piece, the chip, and after that to environment. Heat generated at the shearing plane can make the cutting action easy, but it can flow into the cutting edge and that will negatively affect tool life by shortening it.

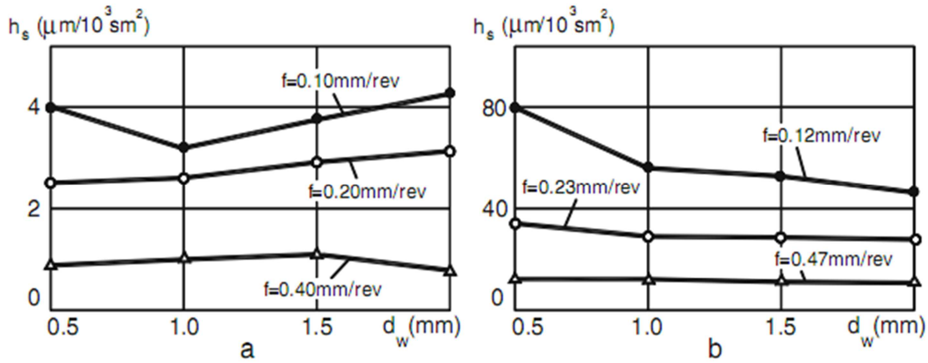

Figure 2.6: (a) Influence of the depth of cut on the tool wear rate with the variable cutting speed optimal for d_w= 0.5mm (b) Influence of the depth of cut on the tool wear rate with the invariable optimal cutting temperature determined for d_w= 1.0 mm

When the depth of cut increases and the uncut chip thickness is kept the same, the specific contact stresses at the tool-chip interfaces, the chip compression ratio (defined as the ratio of the chip and the uncut chip thickness) and the average contact temperature remain unchanged. Therefore, an increase in the depth of cut should not change the tool wear rate if the machining is carried out at the optimum cutting regime. Figure shows the influence of depth of cut on the tool wear rate. In the test, the cutting speed was determined to be optimal for the depth of cut d=0.5 mm and was kept invariable for the depths of cut. As seen, the depth of cut has a very little influence on the tool wear rate. In other series of tests, the optimal cutting temperature was determine for d=1.0 mm and was kept invariable in the test. The test results are shown in b. As seen, the depth of cut has a little influence on the tool wear rate (Viktor ,2006)

A series of experiments was conducted by Choudry and Kishore (2000) to establish relationship between the cutting parameters and the tool wear. Experiments were carried out at various cutting conditions. To reduce the total number of experiments and to obtain data uniformly from all the regions of the selected working area, a factorial design procedure was adopted. A three level factorial design for three cutting parameters was implemented; cutting speed, feed rate and depth of cut were considered as input cutting parameters. So the 3^3 factorial design was implemented. The three levels of all factors shown below:

Table 2.3: 3^3 factorial design

Factors	Low	Medium	High
Cutting speed (rev/min)	90	114	142
Feed Rate (mm/rev)	0.125	0.175	0.20
Depth of cut (mm)	0.8	1.0	1.2

Flank wear occurs on the relief face of the cutting tool and is generally attributed to the rubbing of the too along the machined surface and high temperature causing abrasive and/or adhesive wear, thus affecting tool material properties as well as work piece surface. Flank wear is a mechanically activated wear usually by the abrasive action of the hard work piece material with the cutting tool. The severity of abrasion in cases, where the work piece material contains hard inclusions or when there is hard wear debris from the work piece or the tool, at the interface.(Aruna, 2010)

Flank wear is increasing as the speed increases. Flank wear was observed to be greater at higher cutting speeds. Increase in cutting speed causes higher cutting temperature. Also shorter contact is was observed at chip-tool interface at high speeds. This cause concentration of high cutting temperature very close to the cutting edge. As a result the strength of the tool reduced and when tool rubbed over the workpiece surface at such cutting conditions, flank wear became more. (Liu et al., 2002)

The heat generated in the cutting zone is distributed among the tool, the workpiece, the chip, and after that to the environment. Heat generated at the shearing plane can make the cutting action easy, but it can flow into the cutting edge and that will negatively affect tool life by shortening it. In general, when machining steel with coated carbide tools different tool wear mechanism occur such as abrasion, adhesion, oxidation and even some diffusion which act simultaneously and in proportions depending mainly on the temperature (Usui, 1998). The task of defining which of that mechanism to the cutting speed have been made and some important results have been published. For example, the raise in temperature at the cutting zone occurs basically due to the cutting speed increases

Normally, tool life is influenced mostly by the cutting speed, then by the feed rate, and least by the depth of cut. When the depth of cut is increased to about 10 times greater than the feed, a further increase in the depth of cut will no longer affect the tool life. Conversely, if the cutting speed or the feed is decreased, the increase in the tool life will be proportionately greater than the decrease in the cutting speed or the feed. (Eghawail et al., 2010)

2.9 DESIGN OF EXPERIMENT (DOE)

In machinability studies investigations, statistical design of experiments is used quite extensively. Statistical design of experiments refers to the process of planning the experiment so that the appropriate data can be analyzed by statistical methods, resulting in valid and objective conclusions (Montgomery,1997).

DOE methods such as factorial design, response surface methodology and Taguchi methods are now widely used in place of one-factor-at-a-time experimental approach which is time consuming and exorbitant in cost (Montgomery,1997).

Proper method such as Design of Experiment (DOE) is important in vital study as to be applies to achieve the best result. Design of Experiments (DOE) is widely used in research and development, where a large proportion of the resources go towards solving optimization problems. The key to minimizing optimization costs is to conduct as few experiments and thus helps to reduce costs. Therefore the knowledge is applicable for further use. Generating such as design will provide with a list of all experiments required to be perform and gather enough information for purposes (Brownlee, 1960)

Montgomery (1997) quoted in his research an optimum selection of process condition is extremely important as this one determine surface quality and flank wear phenomena of the manufactured parts. In turning of cutting parameters will cause undesired surface roughness and high tooling cost. In order to decide the surface quality and tool wear the statistical design of experiments (DOE) is used quite extensively. The design of experiments refers to the process of planning of experiments, so that the appropriate data can be analyzed by statistical methods, resulting in a valid and objective conclusion

Design of experiments is a powerful analysis tool for modelling and analysing of the process effect. The experimental design method is an effective approach to optimise the various machining parameters. The selection of such points in the design space is commonly called deign of experiments (DOE) or experimental design. DOE methods can be an important part of a through system optimization, yielding definitive system design or redesign recommendations. These methods also involve the activity experimental planning, conducting experiments, and fitting models to the outputs. An essential ingredient in applying DOE methods is the use of the experimental design can have a large influence on the accuracy and the construction cost of the approximations. In a factorial design creates 3n training data, where n is the number of variables (Montgomery,1997).

Box-Behnken Design is normally use when performing non-sequential experiments. That is, performing the experiment only once. These designs allow efficient estimation of the first-order coefficients. Because Box-Behnken Design has fewer design points, they are less expensive to run than central composite designs with the same number of factors. Box-Behnken Design do not have axial points, thus can be sure that all design points fall within the safe operating. Box-Behnken Design also ensures that all factors are never set at their high levels simultaneously (Box and Wilson, 1950)

Various coefficient of determination, R^2 was checked in order to determine whether the model actually describes the experimental data. R^2 coefficient has values between 0 and 1. In addition to the above, the adequacy of the model is also investigated by the examination of residuals. The residuals, which are the difference between the respective, observe responses and the predicted responses are examined using the normal probability plots of the residuals and the plots of the residual versus the predicted response. If the model is adequate, the points in the normal probability plots of residuals should form a straight line. On the other hand the plots of the residuals versus the predicted response should be structure less, that is, they should contain no obvious patterns (Box and Wilson, 1950).

2.10 ANALYSIS OF VARIANCE (ANOVA)

ANOVA was developed that initially dealing with agricultural data, this methodology has been applied to a vast array of other fields. This analysis is use to claims involving three or more means. F-test is used to test a hypothesis concerning the means of three or more populations. In ANOVA, even three or more means are compared: variances are used in the test instead of means. Two different estimates of the population variance of the F-test are made:

1. Between group variance-involving finding the variance for the means
2. Within the group variance-Computing the variances using all the data and is not affected by the differences in the means.

Since variation is a large part of the discussion relative to the quality, analysis of variance (ANOVA) is the statistical method used to interpret experimental data and make necessary decision. ANOVA is a statistically based decision tool for detecting any difference in average performance of groups of items tested. ANOVA is a mathematical technique which breaks total variation down into accountable sources and total variation is decomposed into its appropriate components (Callister and William, 1994)

Analysis of Variance (ANOVA) is a statistical test for detecting differences in group means when there is one parametric dependent variable and other more independent variable. The ANOVA table is one of the ways to test the significance of the effect. The ANOVA table shows the sum of squares (SS) for total variation of response into sums of squares for individual effects and residual variation (error). The R-square and adjusted R-square values are estimates of the 'goodness of fit' of the line. They represent the % variation of the data explained by the fitted line; the closer the points to the line, the better the fit. Adjusted R-squared is not sensitive to the number of points within the data. R-squared is derived from (Callister and William D, 1994) :

$$\text{R-square} = 1 - [\text{Residual SS}/\text{Total SS}] \qquad \text{Eq. (2.3)}$$

2.11 SUMMARY

From the literature review, it is found that the tool wear mostly depend of the cutting parameters. The interaction between the different cutting parameters might have significant effect on the tool wear. In this study, three cutting parameters were selected to study which is cutting speed, depth of cut and feed rate.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, it will discuss about the methods, rules and process that will be used in this project. The main objective of project methodology is to show the flow of experiments to be done from beginning until the analysis of the experiments. Besides, in this chapter some of the possibilities will be outlined and provide a rational for the research methodology which was ultimately chosen. Important method such as Heat Treatment, material selection and more will be highlighted in this chapter.

Firstly, to prepare the work pieces AISI 1065 were cut into 27 work pieces. Then, the composition of the material was check using L00 LT-MSI Arc Spark Spectrometer. They will be heated to critical temperature and then quenching in water. Hardness number of the work pieces was found out using Vickers Hardness Test and Vickers hardness number (VH) is then obtained. The hardness of the work piece before heat treatment and after heat treatment was then compared.

From STATISTICA software, design of experiments is run to know the suitable experiments of runs. Using 3^3 factorial, the number of experiments is 27 with three different parameters use that are speed of the machine, depth of cut and also the feed rate.

The work pieces are then go through turning process using Conventional Lathe Machine (PINACHO) S-90VS/180. The tool wear from the turning process is analyzed using Microscope MarVision MM320 and Quadra check 300.

3.2 METHODOLOGY FLOW CHART

Methodology flow chart is as guidelines and the sequences in this research. In this study, dry machining had been identified as an economical way to reduce the usage of cutting fluids that. The literature review that related to the research was gathered from journals, reference books, articles and internet. In this research, Design of Experiment (DOE) with Box-Behnken designs was used in this study. By using "Table of Run" generated by the STATISTICA software, experiment is performed and then the data is collected and analyzed with Analysis of Variance (ANOVA) to determine the significant factors in this study. Figure 3.1 illustrates the methodology of this research in flow chart.

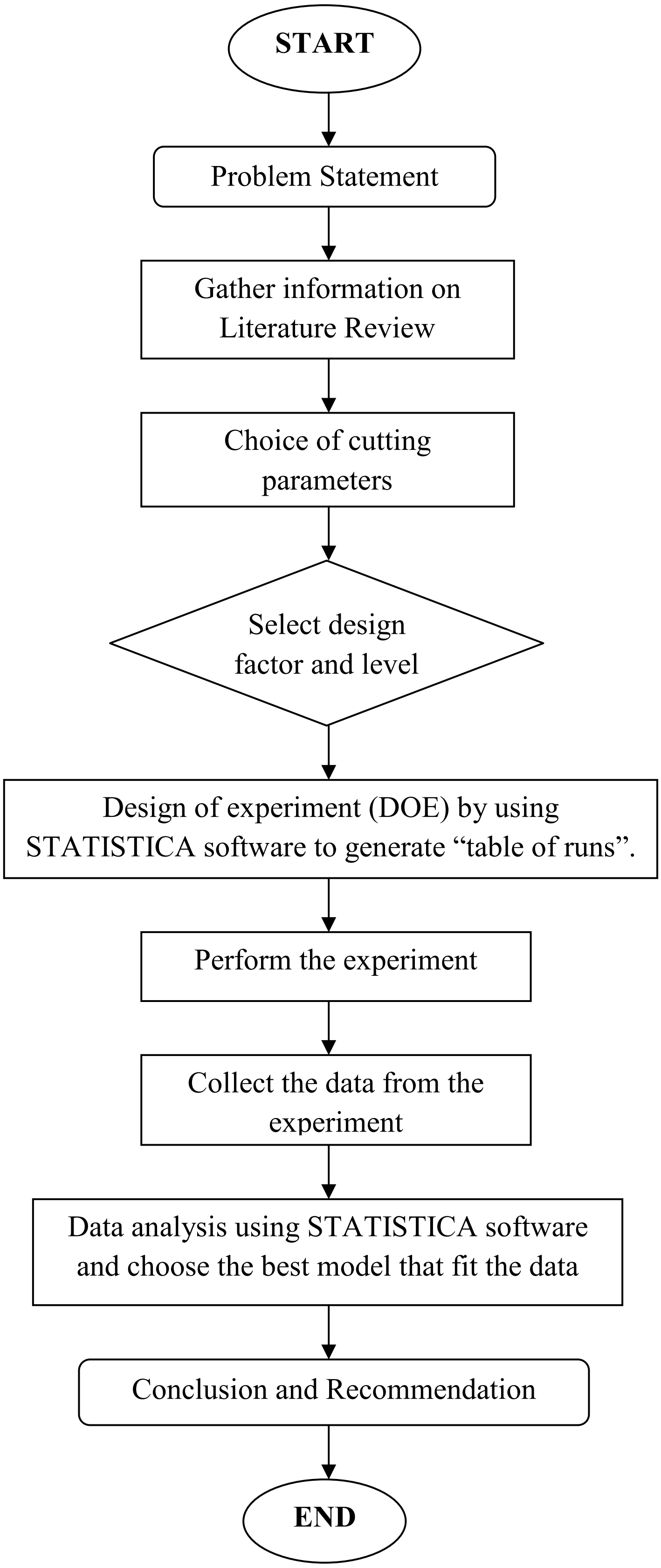

Figure 3.1: Methodology Flow Chart

3.3 PREPARATION OF SPECIMEN

AISI 1065 which is widely used in engineering application is considered in this project. Firstly, the material are cut into smaller part with dimensions height 100 mm and diameter 30mm using band saw cutting machine S-300HB in Figure 3.3.. 27 work pieces will be cut. Figure 3.2 shows the drawing of the work piece used in this project.

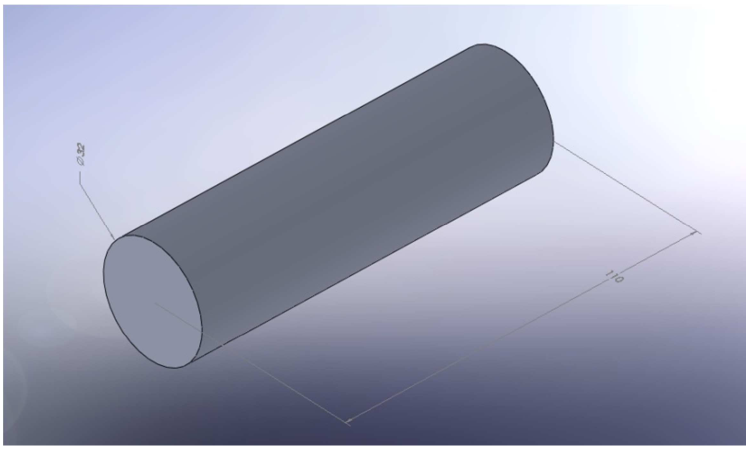

Figure 3.2: Drawing of the work piece used

Figure 3.3: Band saw cutting machine S-300HB

Figure 3.4: Cutting process of the work pieces

3.3.1 Material Selection

AISI 1065 is a categorized as high carbon steel. The material's composition for the specimen is tested using the L00 LT-MSI Arc Spark Spectrometer in Figure 3.5. The material composition is tested with 3 sparks and the average value is calculated. The composition of the material is shown in the Table 3.1. The result is compared with the material composition chart and the type of material is determined.

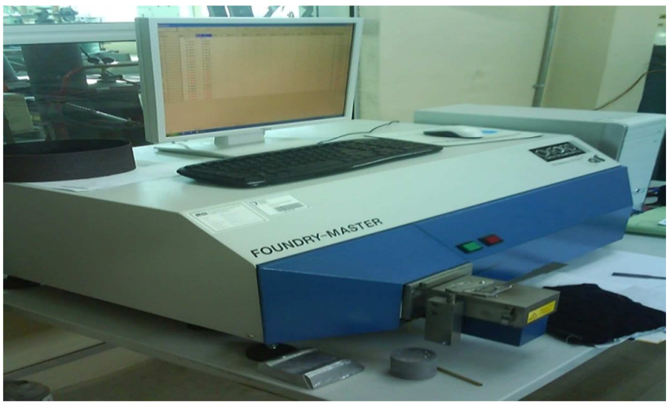

Figure 3.5: L00 LT-MSI Arc Spark Spectrometer

Table 3.1: Chemical composition of AISI 1065

Content	Composition (%)
Carbon	0.666
Silicon	0.220
Manganese	0.623
Sulphur	0.003
Phosphorus	0.003

Table 3.2: Mechanical properties AISI 1065

Properties	Value
Density (x1000kg/m3)	7.7-8.03
Poisson's Ratio	0.27-0.30
Elastic Modulus (Gpa)	190-210
Tensile Strength (Mpa)	640
Yield strength (Mpa)	495
Elongation (%)	10
Reduction in Area (%)	45

3.4 HEAT TREATMENT

The specimens are heated uniformly to 800-900°C in a high intensity flame furnace for more than 30 minutes to homogenize specimens to the temperature. Then the furnace was switched off and the specimens are ready taken out. Figure 3.6 shows the heating of the work pieces in the furnace.

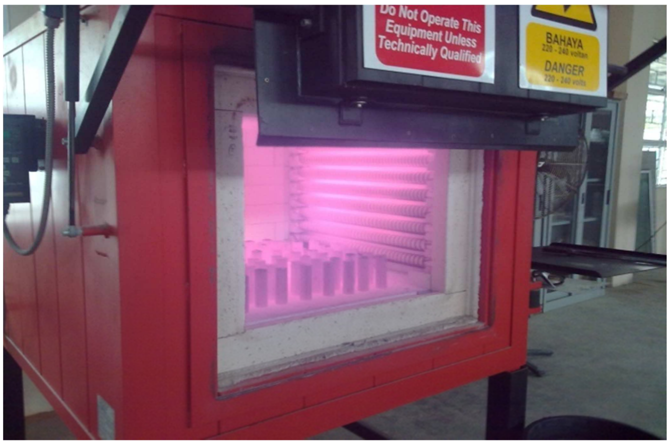

Figure 3.6: Heating the work pieces

3.4.1 Quenching

Heat treated work pieces were quenched that involved the rapid cooling in selected quenching medium. Work pieces are directly quenched in water as shown in Figure 3.7 and the work pieces will attain the bath temperature within a few minutes.

Figure 3.7: Quench in water

3.5 HARDNESS TEST

The Vickers hardness test is used to determine a material ability to resist deformation from a standard source. This test is easier than others test because the calculations involved are independent of indenter size, and the hardness values are determined by measuring the depth of an area of indentation left by an indenter. The surface of specimens should be cleaned before hardness test so that the result from the Vickers hardness test performed is accurate. Nine readings were taken. Three readings at the centre of the specimen and the rest is near outer the specimen. The hardness numbers from the specimens are obtained from Vickers hardness test machine shown in Figure 3.8.

Figure 3.8: Vickers hardness test machine

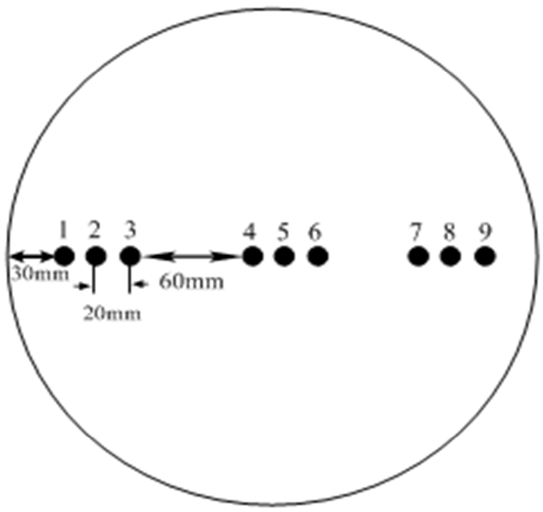

Figure 3.9: View of indentation on the work piece

Figure 3.9 shows the indentation done on the work piece. Nine indentations had been done and the average value is calculated. All Vickers ranges use a 136° pyramidal diamond indenter that forms a square indent. The indenter is pressed into the work piece by controlled test force. The force that been touch the specimen is 10 seconds until 15 seconds. After the indenter is removed from the specimen surface, a square shape called the diamond is appears on the work piece. The size of the square shape is determined by measuring the two diagonal of the square indent. The average of the two diagonals is used to calculate Vickers hardness value. The Vickers number, which normally ranges from HV 100 to HV1000 for metals, will increase as the sample gets harder.

3.6 SELECTION OF PARAMETERS

Before machining the work pieces, there are three different parameters used that are depth of cut, speed of machine and feed rate need to determine. To control the parameters, STATISTICA software will be used. It is use to optimize the amount of information needed for use in making management decisions. 3^3 full factorial design of experiment (DOE) is used in STATISTICA software to plan and perform the experiment systematically so that any possible experimental error would be minimized.

Design of Experiment (DOE) is started and *3** (K-p) and Box-Behnken designs* is chosen. Click OK.

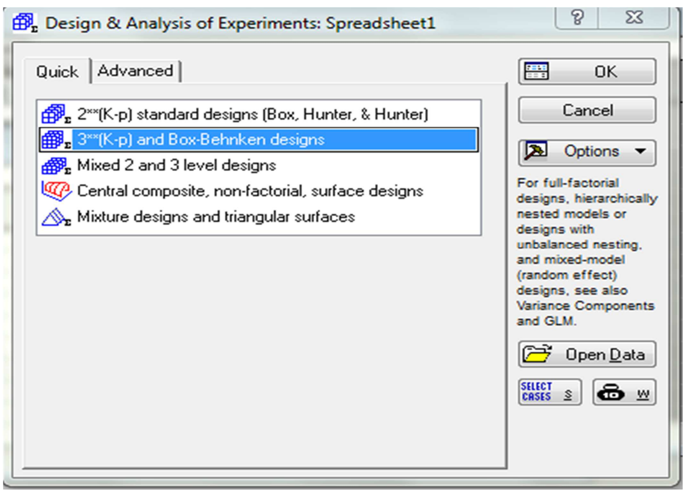

Figure 3.10: 3** (K-p) and Box-Behnken designs

From the *Design & Analysis of Experimental with Three-Level Factors* box, *Design experiment* tab is selected. Factors/blocks/runs of 3/1/27 are chosen and click OK.

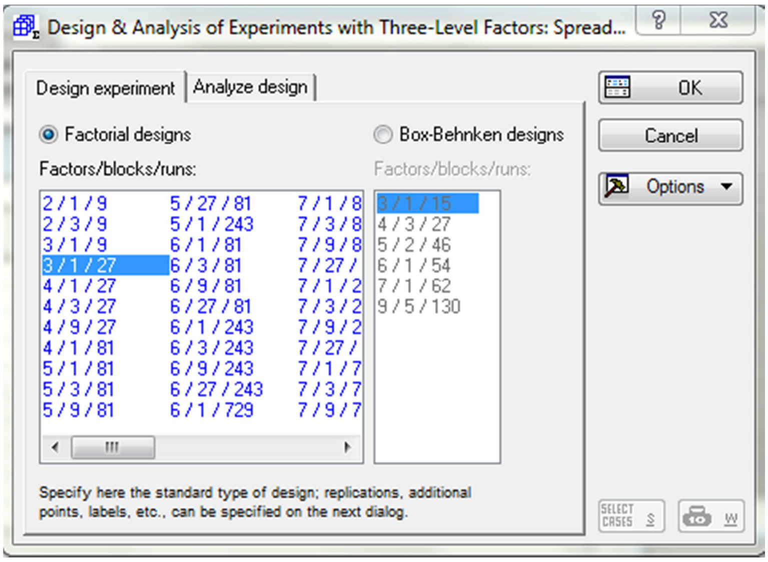

Figure 3.11: Design three-level factor

From the *Design of an Experiment with Three-Level Factors* box, click on *Add to design* tab and enter value 1 in the *Number of blank columns* edit field. From *Quick* tab, select the Change factor names, values, etc and enters name and values of parameters in the *Summary for Variables (Factors)* box. The parameters used are indicated in the Table 3.3.

Table 3.3: Selection of factors and the values

Factor	Low	Medium	High
Speed (rev/min)	90	120	150
Depth of cut (mm)	0.8	1.0	1.2
Feed rate (mm/rev)	0.13	0.18	0.22

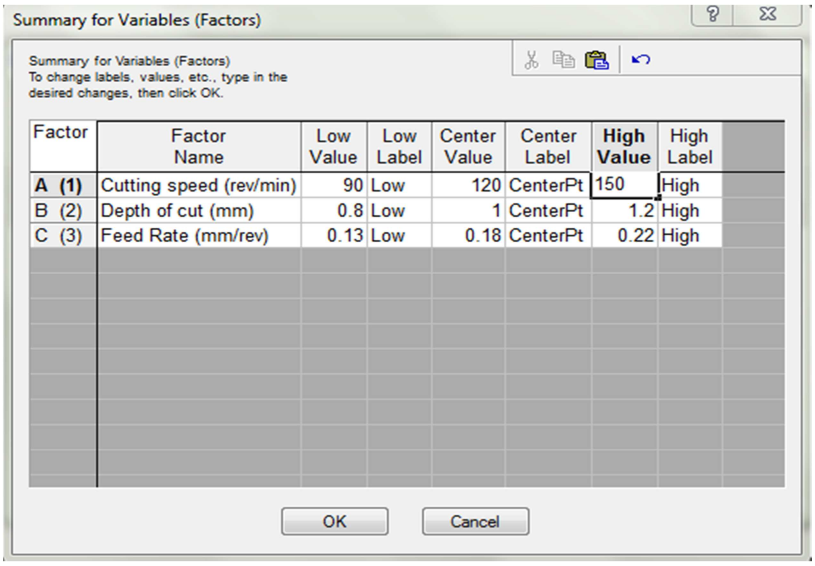

Figure 3.12: Summary for variables

Then, click *Summary: Display design* button to display the table of runs.

Standard Run	3**(3-0) full factorial design, 1 block , 27 runs ([No active dataset])		
	Cutting speed (rev/min)	Depth of cut (mm)	Feed Rate (mm/rev)
24	150.0000	1.000000	0.220000
17	120.0000	1.200000	0.180000
20	150.0000	0.800000	0.180000
2	90.0000	0.800000	0.180000
11	120.0000	0.800000	0.180000
10	120.0000	0.800000	0.130000
7	90.0000	1.200000	0.130000
12	120.0000	0.800000	0.220000
1	90.0000	0.800000	0.130000
6	90.0000	1.000000	0.220000
4	90.0000	1.000000	0.130000
13	120.0000	1.000000	0.130000
5	90.0000	1.000000	0.180000
3	90.0000	0.800000	0.220000
19	150.0000	0.800000	0.130000
22	150.0000	1.000000	0.130000
21	150.0000	0.800000	0.220000
14	120.0000	1.000000	0.180000
8	90.0000	1.200000	0.180000
9	90.0000	1.200000	0.220000
26	150.0000	1.200000	0.180000
16	120.0000	1.200000	0.130000
18	120.0000	1.200000	0.220000
25	150.0000	1.200000	0.130000
23	150.0000	1.000000	0.180000
27	150.0000	1.200000	0.220000
15	120.0000	1.000000	0.220000

Figure 3.13: Table of runs

3.7 TURNING OPERATION

The prepared specimen is undergoing dry turning operation according to the parameters that have been determined in Figure 3.13. Coated carbide insert cutting tool is used for every experiment. The machine that is use is Conventional Lathe Machine (PINACHO) S-90VS/180 as shown in Figure 3.14.

RPM use is calculated using the formula

$$\text{RPM} = \frac{CS\ X\ 1000}{\pi d} \qquad \text{Eq. (3.1)}$$

Where:

CS= Cutting speed (rev/min)

d= Diameter of work piece (mm)

Example of RPM calculation:

For d = 30 mm and cutting speed 90 rev/min

$$\text{RPM} = \frac{90x1000}{\pi x30} = 955$$

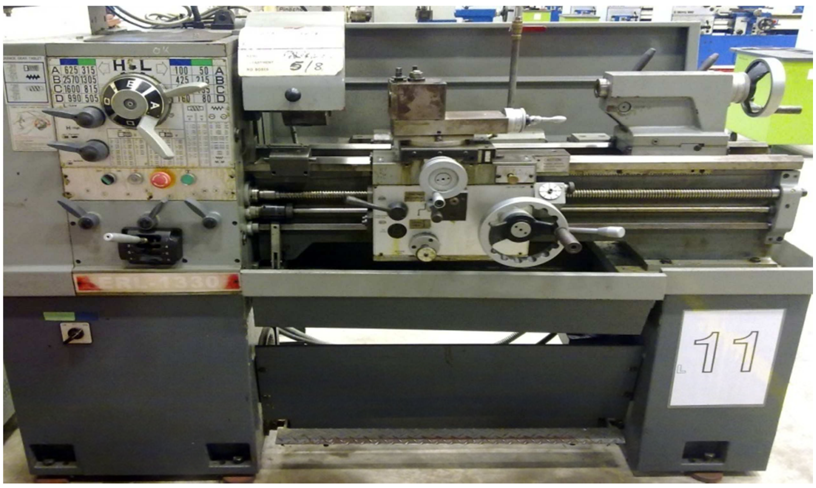

Figure 3.14: Conventional Lathe Machine

Before switch ON the machine, the machine was make sure clear from any previously used materials, lubrication oil and make sure the spindle control at the apron is in the neutral position. The coated carbide insert used in the experiment was inserted on the tool holder. The work piece was clamped on the chuck tightly. The desired spindle speed, feed rate were choose. To start the spindle turning forward (counter clockwise), the spindle control level located on the right side of the carriage apron was pull up. The feed axis is push up for forward feed (towards the headstock).

Turning operation started based on the parameters decided for 7 rounds. After 7 rounds of turning the machine is stop. To stop the spindle, the spindle control was moved to the "neutral" position by pushing it down from the "forward" position. For an emergency "STOP" step on the foot brake bar or depress the Emergency "STOP" button on the power panel. The machined work piece was taken out from the chuck. The coated carbide insert also took out from the tool holder. New work piece was then clamped and the same coated carbide insert was clamped back to the tool holder but with the new side. Coated carbide insert have 6 sides that can be used differently.

Figure 3.15: Coated carbide insert

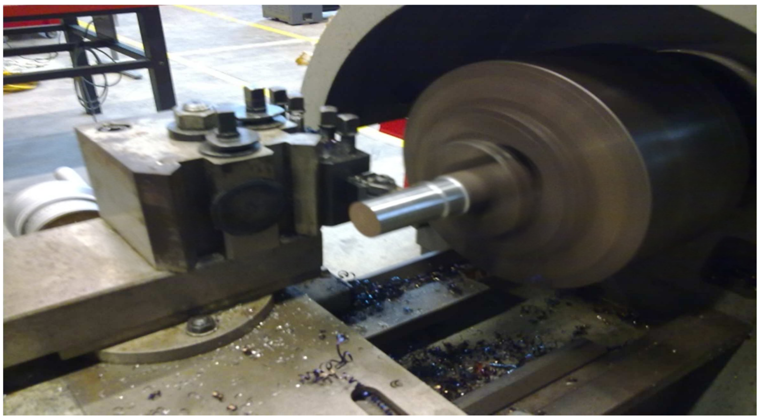

Figure 3.16: Turning operation

Some important safety while doing turning process:

- Do not wear loose clothing when operating the lathe machine
- Ensure the spindle start lever on the carriage is in the neutral position prior to turning the power on to the lathe.
- Ensure the proper use of safety equipment such as safety glasses when operating the lathe.

3.8 DATA RECORDING

The carbide cutting tool from every experiment will be investigated. The tool wear is seen and measured by using the Microscope MarVision MM320 and Quadra check 300.

Figure 3.17: Microscope MarVision MM320 and Quadra check 300

First of all, the coated carbide insert that had been used in turning process will be placed under the microscope MarVision MM320 and observed using 3.0 × magnifications to identify the tool wear. After that, a point was mark at the end of wear. Another point will be marked at the other end of the wear. The distance between the points were automatically determined by the operating unit of the microscope. The procedures were repeated with different side of the tool wear.

3.9 DATA ANALYSIS

After conducted the experiment, the analysis need to be done in order to identify the significance of each factor used in the research. STATISTICA software was used to perform analysis of variance (ANOVA). The analysis of variance (ANOVA) is most widely use method of statistical analysis of quantitative data. The purpose of analysis of variance (ANOVA) is to test for significant differences between means in different groups or variables (measurements), usually arranged by an experiment in order to evaluate the effects of different treatments or experimental conditions, or combinations of treatment or conditions.

Firstly, the results obtained from the experiment were filled in the the next column of "Table of Runs" produced before. From the *Design & Analysis of Experimental with Three-Level Factors* box, *Design experiment* tab is selected. Then *Analyze Design* tab was click and select *Variables* tab. The analysis is started by specify the Tool wear length as the dependent variables and cutting speed, depth of cut and feed rate as the independent variables. Figure 3.18 shows the interface of the STATISTICA when choose the dependent and independent variables.

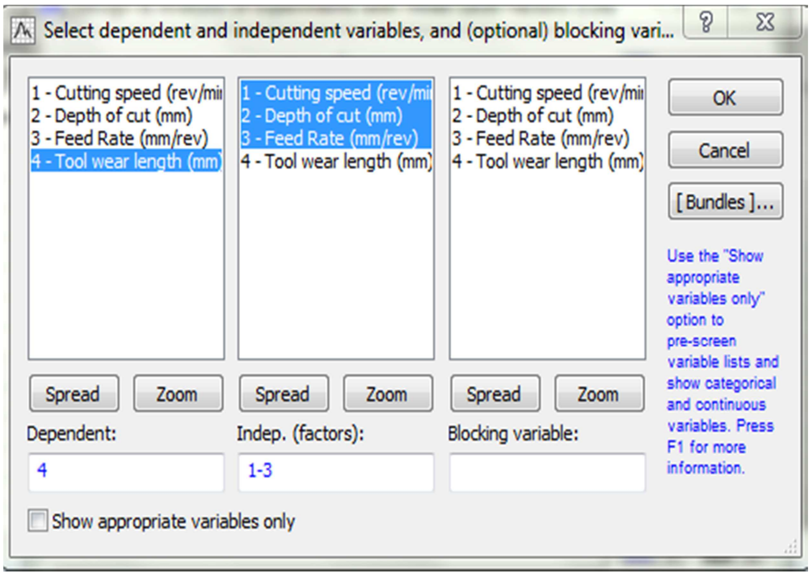

Figure 3.18: Dependent and independent variables

Analysis of experiment with three level factors was appeared on the screen. Figure 3.19 shows the interface of STATISTICA when selected the model. The Model tab is click and firstly *No interaction* model was click. Back to *Quick tab*, *Centered & scaled polynomial* check box was choosing. When the Use centered & scaled polynomial check box was selected, then the origin factor settings are recorded so that the effect estimates are comparable in size to the linear and main effect estimates. If the check box was cleared, the coding for the quadratic main effect is the result of the squaring the ± 1coding for the linear main effect. In that case, the effect estimates are not comparable in size to the linear effect estimates. Then, the *Summary: Effect estimates* and *ANOVA table* tab were click.

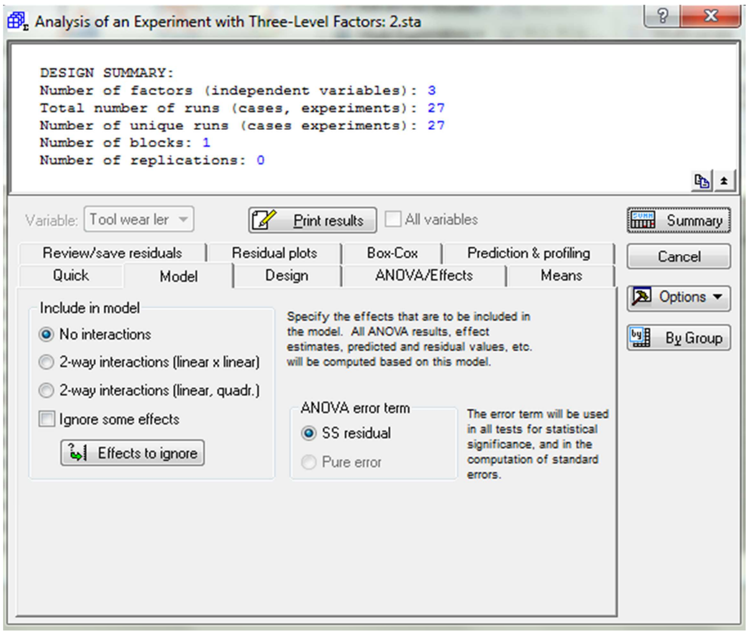

Figure 3.19: Selection of model

To test the significance of the factors in the experiment, the different models were analyzed. From the ANOVA table result, the P-values indicate the significance level of the factor. Before decide to accept the current model, it is important to examine the fitness of the current model. If there is an overall lack of fit of the current model, the data was then analyzed by using more complicated model. The residual variability is significantly larger than the pure variability, then one can conclude that there is still some statistically significant variability left that is attributable to difference between the groups, and hence, that there is an overall lack of fit of the current model. In that case, try more complex model.

Then, the analysis was proceeding with two-way interaction (linear x linear). If there is an overall lack of fit in the current model, the analysis is proceed with more complicated model of the two-way interaction (linear, quadratic). Interaction between two variables is present if R-square of two-way ANOVA is greater than no interaction model. The three different models were compared and analyzed. The fitness of every model was evaluated.

The value of the P-value represents a decreasing index of the reliability of a result (Brownlee, 1960). The higher the P-value, the less we can believe that the observed relation between variables in the sample is a reliable indicator of the relation between the respective variables in the population.

From different analysis models, different P-value and R-square were obtained. P-value represents the significance level of the factors. The P-value represents the probability of error that is involved in accepting the observed results as valid. The P-values in ANOVA table were used to determine the significance level of the parameters.

From the Lewicki and Hill (2006), the criteria used is this research were results that yield P-value$\leq$ 0.05 are considered borderline statistically significant but that this level of significance still involves a pretty high probability of error (5%). Results that are significant at the P-value$\leq$ 0.01 are commonly considered statistically significant and P-value$\leq$ 0.05 or P-value $\leq$ 0.001 levels are often called highly significant.

From the *Prediction & profiling* tab, *Predicted vs. observed* tab was choosing and the scatter plot was plotted.

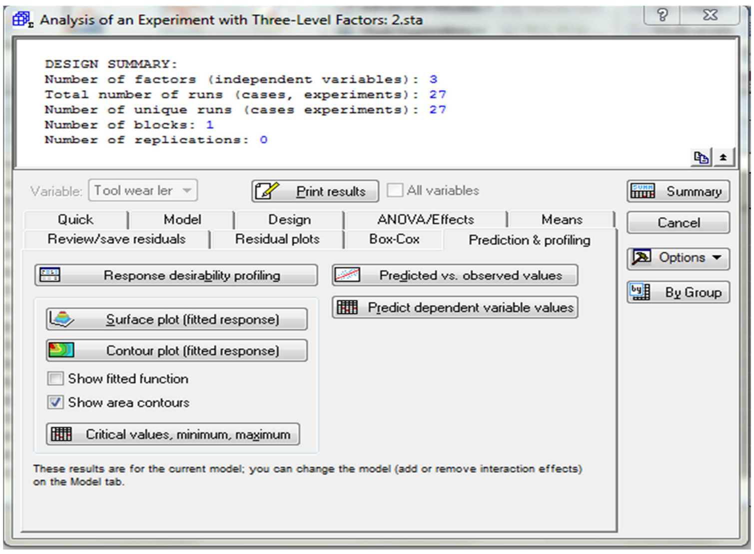

Figure 3.20: Predicted vs. observed scatter plot selection

In order to evaluate the appropriate of a model, some ways can be used such as analysis of variance explained, normal probability plots, plots of observed versus predicted values, plot of fitted function and goodness of fit Chi-square. In this analysis, analysis of variance explained and scatter plot of observed versus predicted values were used to evaluate the overall fitness of the model.

Scatter plot of observed versus predicted values was used to evaluate the goodness of fit of the model. As the point falls onto and follows the straight line approximately, it indicating the straight line and dispersed, it indicating lack of fit of the current model. A satisfactory fit model is sufficient to explain the relationship between the factors and response variable. Both R-square values and fitness of model must achieve satisfactory before a particular model was accepted.

The R-square or coefficient of determination value can be interpreted as the proportion of variability around the mean for the dependent variable that can be accounted for by the respective model. The R-square value is an indicator of how well the model fits the data. If R-square value was 0.4 then the variability of the Y values around the regression line is 1-0.4 times the original variance. In other word, 40% of the original variability has been explained and 60% left residual variability.

CHAPTER 4

RESULTS & DISCUSSION

4.1 INTRODUCTION

Chapter 4 demonstrates the evaluation using Analysis of variance (ANOVA) to analysis the total tool wear and then determine which parameters most influence tool. Design of experiment method was used by implementing the Box-Behken design to identify the main effects of the parameters. Statistical analysis was performed in order to identify the significance of each factor.

4.2 HARDNESS TEST

4.2.1 Experimental Analysis

Table 4.1: Vickers Hardness value

Indentation No	Vickers Hardness (HV) before hardening	Vickers Hardness (HV) after hardening
1	164.3	221.3
2	179.6	224.8
3	178	249
4	174	224
5	174.5	195.2
6	179	206.8
7	220.2	214.2
8	195	190.9
9	201.1	235.5
	Average = 185.08	**Average** = 217.97

Table 4.1 shows the hardness number (HV) before the heat treatment and after the heat treatment process. Nine different values illustrate the nine indentations from Figure 3.8 done on the work piece before the average value is calculated. The average value of hardness increased from 185.08 before heat treatment to 217.97 after heat treatment process. The percentages of changes were determined by using the Equation (4.1).

$$\text{Percentage of changes} = \frac{\text{New value} - \text{previous value}}{\text{Previous value}} \times 100\% \qquad \text{Eq. (4.1)}$$

After heat treatment of the work piece, the percentage of changes in hardness was approximately 17%.

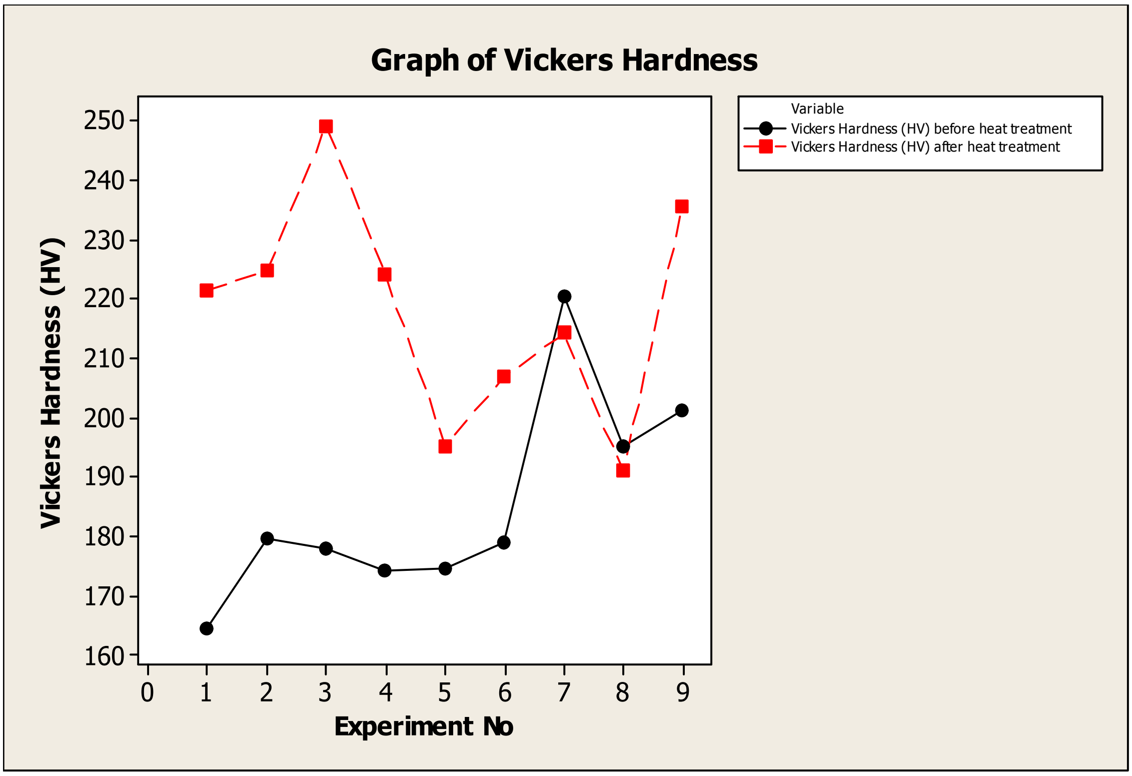

Figure 4.1: Graph of Vickers Hardness

Figure 4.1 shows the Vickers hardness value versus to the number of experiment done. Experiment no indicates the position of the hardness test done as indicated in the previous chapter in Figure 3.9. From the Figure 4.1, the graph before heat treatment (black line) increases initially but then shows the downward movement before increase a lot at the experiment no 7. After that, hardness value decrease. The graph after heat treatment (red line) shows an increment moderately before decrease significantly. The hardness values were then start rising back before drop slightly and rise again.

4.2.2 Discussion

Based on the Table 4.1, the average value of hardness before heat treatment is 185.08 and the average value of hardness after the heat treatment is 217.97. The higher the hardness value, the material is harder.

This experimental result agree to the research done by Rajan T.V and Sharma A (1989) that the heat treatment process increase the hardness of the material as the material undergoes phase microstructure and crystallographic changes.

As indicated in the Figure 4.1, the hardness value after the heat treatment is not uniform at every indentation. Hardness value is mostly higher at the early indentation of the outer surface of the material compared at the centre of the work piece. According to the Mamoru O. Yukito T and Histoshi K (1990) in plain carbon steel, only the first 1/8 to 3/8 inches near the surfaces is quenched rapidly enough to form 100% martensite hard steel. The deeper sections contain progressively softer microstructures that indicated the lower hardness value. This might be because work piece that placed near to the electrical coil are heated more compared to the others. This will cause the non-uniform heating of the work piece during the heating process in the furnace.

4.3 IMPACT OF CUTTING PARAMETERS TO THE TOOL WEAR

Standard Run	3**(3-0) full factorial design, 1 block , 27 runs ([No active dataset])			
	Cutting speed (rev/min)	Depth of cut (mm)	Feed Rate (mm/rev)	Tool wear (mm)
24	150.0000	1.000000	0.220000	1.175
17	120.0000	1.200000	0.180000	0.867
20	150.0000	0.800000	0.180000	0.964
2	90.0000	0.800000	0.180000	0.721
11	120.0000	0.800000	0.180000	0.863
10	120.0000	0.800000	0.130000	0.786
7	90.0000	1.200000	0.130000	0.684
12	120.0000	0.800000	0.220000	0.875
1	90.0000	0.800000	0.130000	0.625
6	90.0000	1.000000	0.220000	0.776
4	90.0000	1.000000	0.130000	0.752
13	120.0000	1.000000	0.130000	0.814
5	90.0000	1.000000	0.180000	0.735
3	90.0000	0.800000	0.220000	0.778
19	150.0000	0.800000	0.130000	0.971
22	150.0000	1.000000	0.130000	0.943
21	150.0000	0.800000	0.220000	1.032
14	120.0000	1.000000	0.180000	0.869
8	90.0000	1.200000	0.180000	0.774
9	90.0000	1.200000	0.220000	0.802
26	150.0000	1.200000	0.180000	0.984
16	120.0000	1.200000	0.130000	0.849
18	120.0000	1.200000	0.220000	0.936
25	150.0000	1.200000	0.130000	0.985
23	150.0000	1.000000	0.180000	0.993
27	150.0000	1.200000	0.220000	1.168
15	120.0000	1.000000	0.220000	0.936

Figure 4.2: Table of runs with the experimental result

Table 4.2: Impact of Cutting Parameters to the Tool Wear

Standard Run	Speed (rev/min)	Depth of Cut (mm)	Feed Rate (mm/rev)	Tool wear (mm)
24	150	1.00	0.22	1.175
17	120	1.20	0.18	0.867
20	150	0.80	0.18	0.973
2	90	0.80	0.18	0.721
11	120	0.80	0.18	0.873
10	120	0.80	0.13	0.835
7	90	1.20	0.13	0.684
12	120	0.80	0.22	0.887
1	90	0.80	0.13	0.625
6	90	1.00	0.22	0.776
4	90	1.00	0.13	0.659
13	120	1.00	0.13	0.854
5	90	1.00	0.18	0.735
3	90	0.80	0.22	0.765
19	150	0.80	0.13	0.879
22	150	1.00	0.13	0.886
21	150	0.80	0.22	1.132
14	120	1.00	0.18	0.805
8	90	1.20	0.18	0.743
9	90	1.20	0.22	0.785
26	150	1.20	0.18	0.986
16	120	1.20	0.13	0.849
18	120	1.20	0.22	0.916
25	150	1.20	0.13	0.896
23	150	1.00	0.18	0.978
27	150	1.20	0.22	1.168
15	120	1.00	0.22	0.907

According to the Table 4.2, the highest length of the tool wear is 1.175 mm with speed 150 rev/min, depth of cut 1.00 mm and feed rate 0.22 mm/rev. The lowest value of tool wear is 0.625 mm with cutting speed 90 rev/min, depth of cut 0.80 mm and feed rate 0.13 mm/rev

4.4 STATISTICAL ANALYSIS: ANALYSIS OF VARIANCE (ANOVA)

Using STATISTICA, ANOVA analysis is used to observed values of tool wear hence determining the significant parameters that influence the machining process. In order to quantify the influence of process parameters and interactions on the selected machining characteristic, analysis of variance (ANOVA) was performed. Three independent variables (cutting speed, depth of cut and feed rate) were investigated using ANOVA with length of tool wear as dependent variable.

By using STATISTICA software, the result obtained from the experiment will be analyzed. Three main models will be specifying in this analysis; No interaction, two way interaction (linear, linear) and two way interaction (linear, quadratic). Then, the data is compared. Interaction between the two variables is present if R-square of two-way ANOVA is greater than no interaction model.

From the Lewicki and Hill (2006), the criteria used is this research were results that yield P-value≤0.05 are considered borderline statistically significant but that this level of significance still involves a pretty high probability of error (5%). Results that are significant at the P-value≤0.01 are commonly considered statistically significant and P-value≤0.05 or P-value ≤0.001 levels are often called highly significant.

Effect estimate for the linear effect (marked by the L next to the factor name) can be interpreted as the difference between the average response at the low and high for the respective factors. The estimate for the quadratic (non-linear) effect (marked by the Q next to the factor name) can be interpreted as the difference between the average response at the centre (medium) settings and the combined high low settings for the respective factors.

Factor	ANOVA; Var.:Tool wear (mm); R-sqr=.91342; Adj:.88745 (3(3-0).sta) 3 3-level factors, 1 Blocks, 27 Runs; MS Residual=.002248 DV: Tool wear (mm)				
	SS	df	MS	F	p
(1)Cutting speed (rev/min) L+Q	0.369807	2	0.184904	82.25362	0.000000
(2)Depth of cut (mm) L+Q	0.002333	2	0.001167	0.51900	0.602912
(3)Feed Rate (mm/rev) L+Q	0.102201	2	0.051101	22.73188	0.000007
Error	0.044959	20	0.002248		
Total SS	0.519301	26			

Figure 4.3: ANOVA table for no interaction model

Based on the table of ANOVA of no interaction model in Figure 4.3, both linear and quadratic are highly significant for the cutting speed with P-values of 0.000000 ($P \leq 0.05$). Refer to the Figure 4.3, the P-value of 0.000007 ($P \leq 0.05$) shows that feed rate is highly significant. As indicates in the table, none of the linear and quadratic effect of depth of cut is significance.

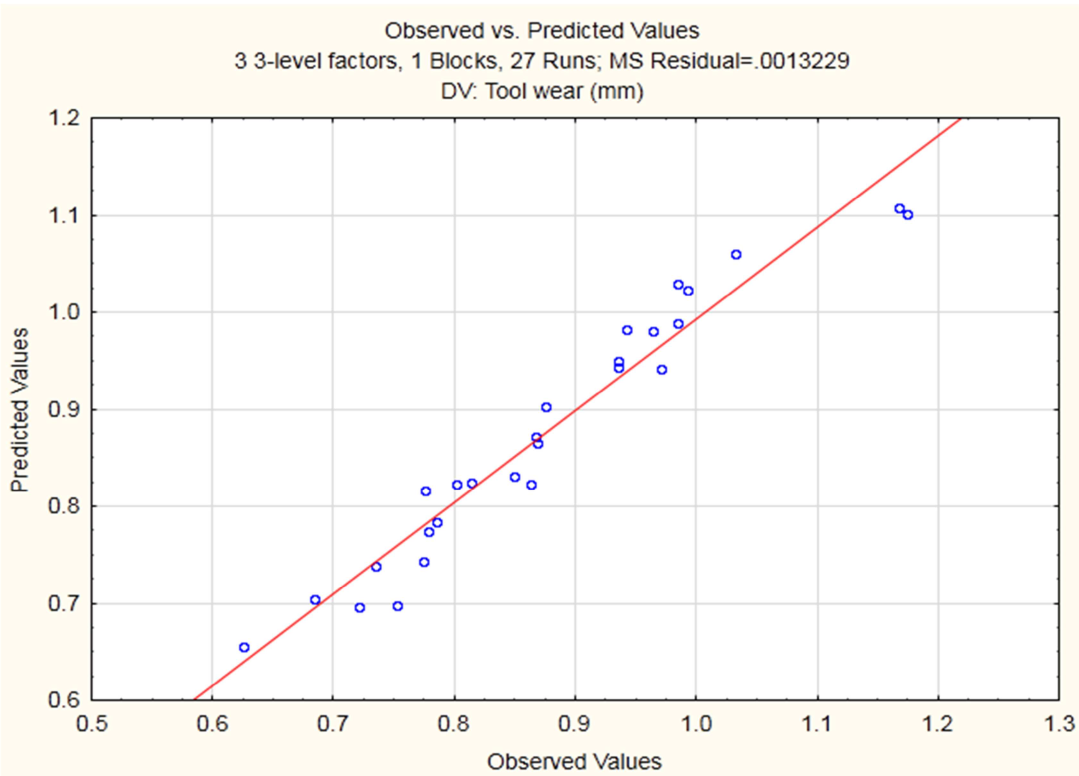

Figure 4.4: Scatter plot of predicted value versus observed value no interaction model

According to the ANOVA table in Figure 4.3, the R-square value is 0.91342 for no interaction model that is approximately 91.34% of the variations of the response variable. The rest 8.66% is residual variability. The R-square or coefficient of determination value is an indicator of how well the model fits the data. Figure 4.4 shows the scatter plot of predicted versus observed values for the length of tool wear. The circle points are the observed values. The points fall onto straight line and dispersed around the upper and lower region of the straight line. The points do not follow approximately the straight line. It indicates the lack of fit of the current model.

A satisfactory fit model is sufficient to explain the relationship between the factors and response variable. Both R-square values and fitness of model must be achieved satisfactory before a particular model was accepted.

The complexity of the model was increase by analyze the ANOVA table for two-way interaction (linear-by-linear). The linear-linear interaction between two variables can be interpreted as half the difference between the linear effect of one factor at the lower and high settings of the other factor. When the behaviour of the response for one factor varies across the level of the other factors, an interaction effect occurs.

	ANOVA; Var.:Tool wear (mm); R-sqr=.94492; Adj:.91576 (3(3-0).sta) 3 3-level factors, 1 Blocks, 27 Runs; MS Residual=.0016826 DV: Tool wear (mm)				
Factor	SS	df	MS	F	p
(1)Cutting speed (rev/min) L+Q	0.362081	2	0.181041	107.5970	0.000000
(2)Depth of cut (mm) L+Q	0.002340	2	0.001170	0.6955	0.512486
(3)Feed Rate (mm/rev) L+Q	0.102201	2	0.051101	30.3704	0.000002
1*2	0.000102	1	0.000102	0.0607	0.808389
1*3	0.016246	1	0.016246	9.6555	0.006403
2*3	0.000007	1	0.000007	0.0043	0.948502
Error	0.028604	17	0.001683		
Total SS	0.519301	26			

Figure 4.5: ANOVA table for two-way interaction (linear-by-linear)

Figure 4.5 shows the table of 2-way interaction (linear-by-linear) model. From the ANOVA table, both linear and quadratic effects on the cutting speed are highly significance with P-values 0.000000 ($P \leq 0.05$). The P-value of feed rate shows

0.000002 (P≤ 0.05) indicates highly significant. Besides, 1*3 interaction (the "cutting speed by feed rate" interaction) is highly significance with P-values 0.06403 (P≤ 0.05).

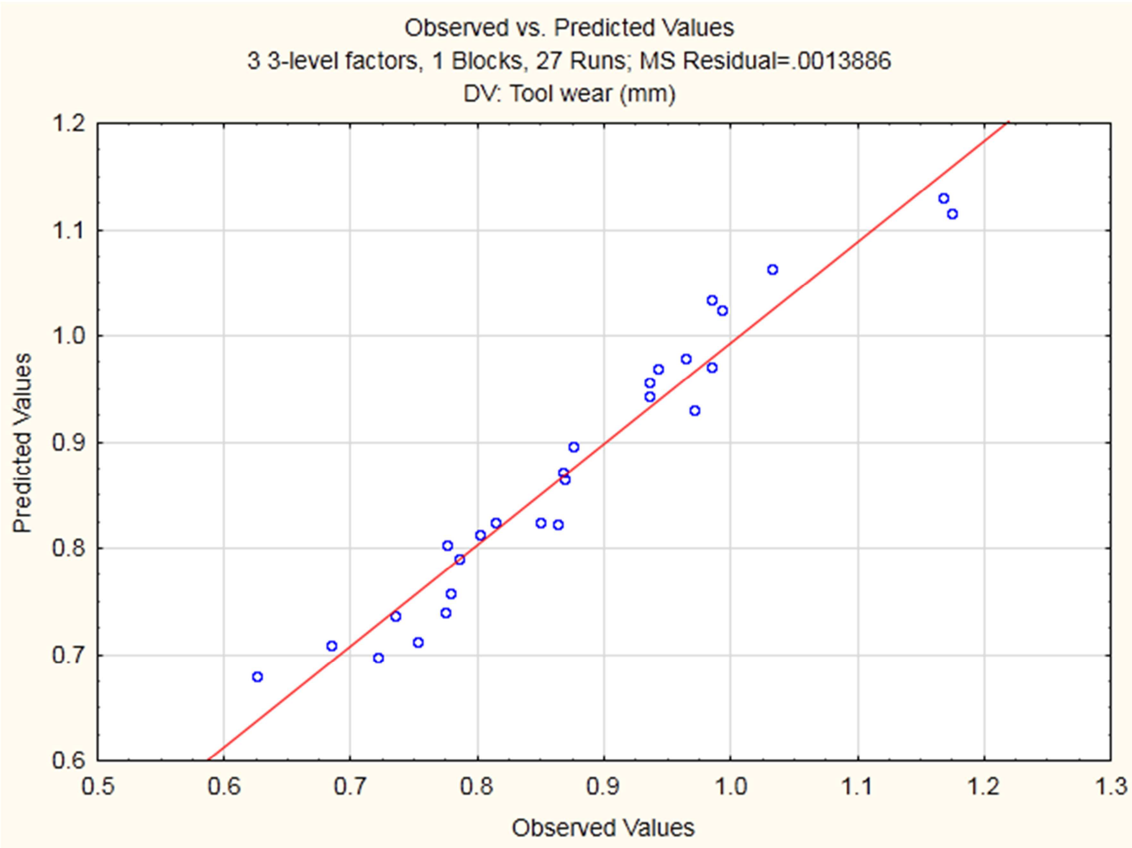

Figure 4.6: Scatter plot of predicted value versus observed value two-way interaction (linear-by-linear)

Figure 4.6 shows the scatter plot of predicted versus observed values for the length of tool wear for the two-way interaction (linear x linear). From the Figure 4.5, the two way interaction (linear x linear) account approximately 94.49% of the variation as R-square value is 0.94492. The rest 5.51% is residual variability. The R-square value has increased from 91.34% to 94.49%. Approximately, 2 points falls onto the straight line and most of the values are close approximately to the straight line compared to the no interaction effect scatter plot.

Before accepting the current model as the best fitted model, the data is analyzed using more complex model that is two-way interaction (linear-by-quadratic). The linear-by-quadratic interaction can be interpreted as half the difference between the linear effect of one factor at the medium setting and the average at the low and high settings of the other combined.

Factor	ANOVA; Var.:Tool wear (mm); R-sqr=.99584; Adj:.98647 (3(3-0).sta) 3 3-level factors, 1 Blocks, 27 Runs; MS Residual=.0002702 DV: Tool wear (mm)				
	SS	df	MS	F	p
(1)Cutting speed (rev/min) L+Q	0.361909	2	0.180955	669.6285	0.000000
(2)Depth of cut (mm) L+Q	0.002337	2	0.001169	4.3246	0.053308
(3)Feed Rate (mm/rev) L+Q	0.102201	2	0.051101	189.0993	0.000000
1*2	0.000946	4	0.000236	0.8751	0.519238
1*3	0.040324	4	0.010081	37.3052	0.000032
2*3	0.001527	4	0.000382	1.4131	0.313154
Error	0.002162	8	0.000270		
Total SS	0.519301	26			

Figure 4.7: ANOVA table for two-way interaction (linear-by-quadratic)

Figure 4.7 shows the table of 2-way interaction (linear x quadratic) model. From the ANOVA table, both linear and quadratic effects on the cutting speed and feed rate are highly significance with P-values 0.000000 (P≤ 0.05). Besides, 1*3 interaction (the "cutting speed component by feed rate component" interaction) is highly significance with P-values 0.00032 (P≤ 0.05).

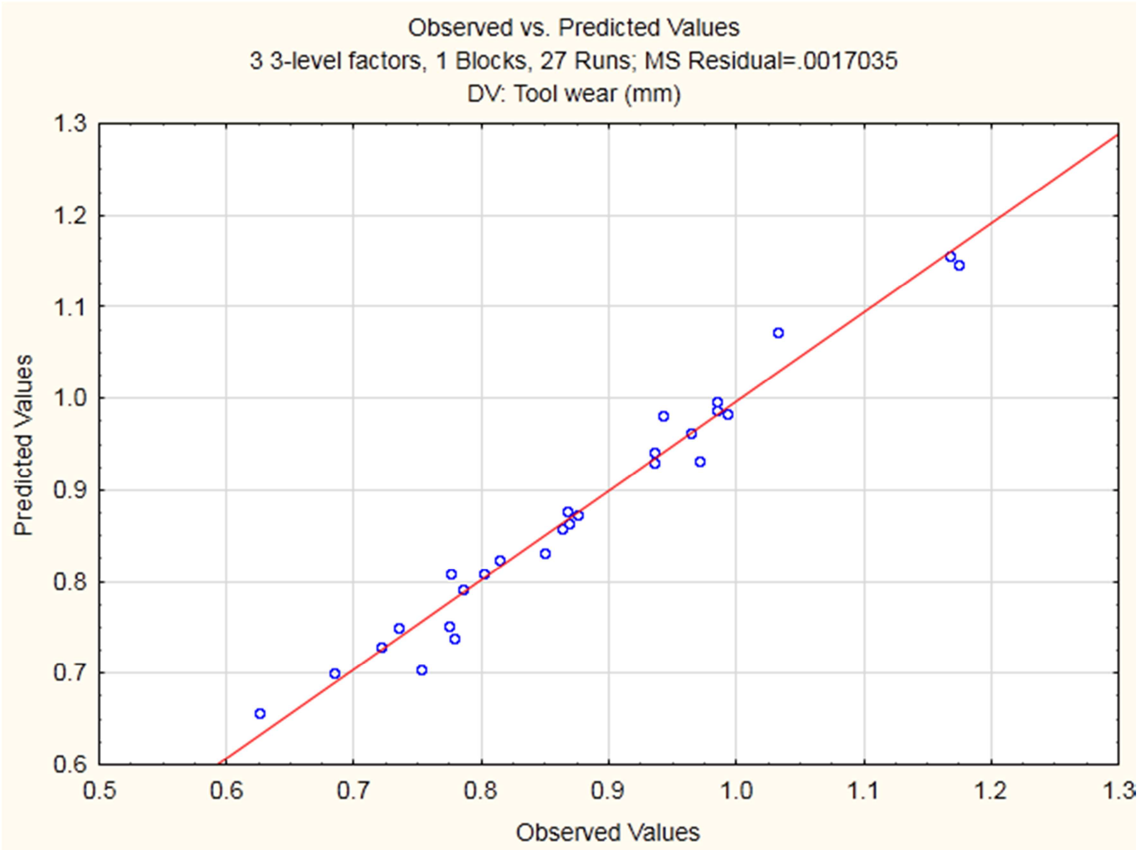

Figure 4.8: Predicted value versus observed value two-way interaction (linear-by-quadratic)

From Figure 4.8, the scatter plot shows the predicted versus observed values of tool wear. The circle points are the observed values. The model explains approximately 98.65% of the variations of the response variable as indicated by the R-square value 0.98647. The R-square value increase from 94.49% in the 2-way interaction (linear-by-linear) model to 98.65%. Approximately the rest 1.35% variation is residual variability. Approximately 21 points fall on the straight line and it indicate a satisfactory fit of the model. It shows sufficient relationship between the variables. This 2-way interaction model (linear-by-quadratic) was sufficient to describe the relationship between the factors and the response variables.

From the analysis of variance with three different model (no interaction, two-way interaction linear x linear and two-way interaction linear x quadratic) shows that two-way interaction model (linear x quadratic) was the best fitted model as it describe the relationship between the variables. From the analysis, cutting speed is highly significant. The feed rate is the major influence of tool wear. Depth of cut does affect the tool wear but its effect was negligible compared to cutting speed and feed rate. There was also significant interaction between cutting speed and feed rate in this analysis.

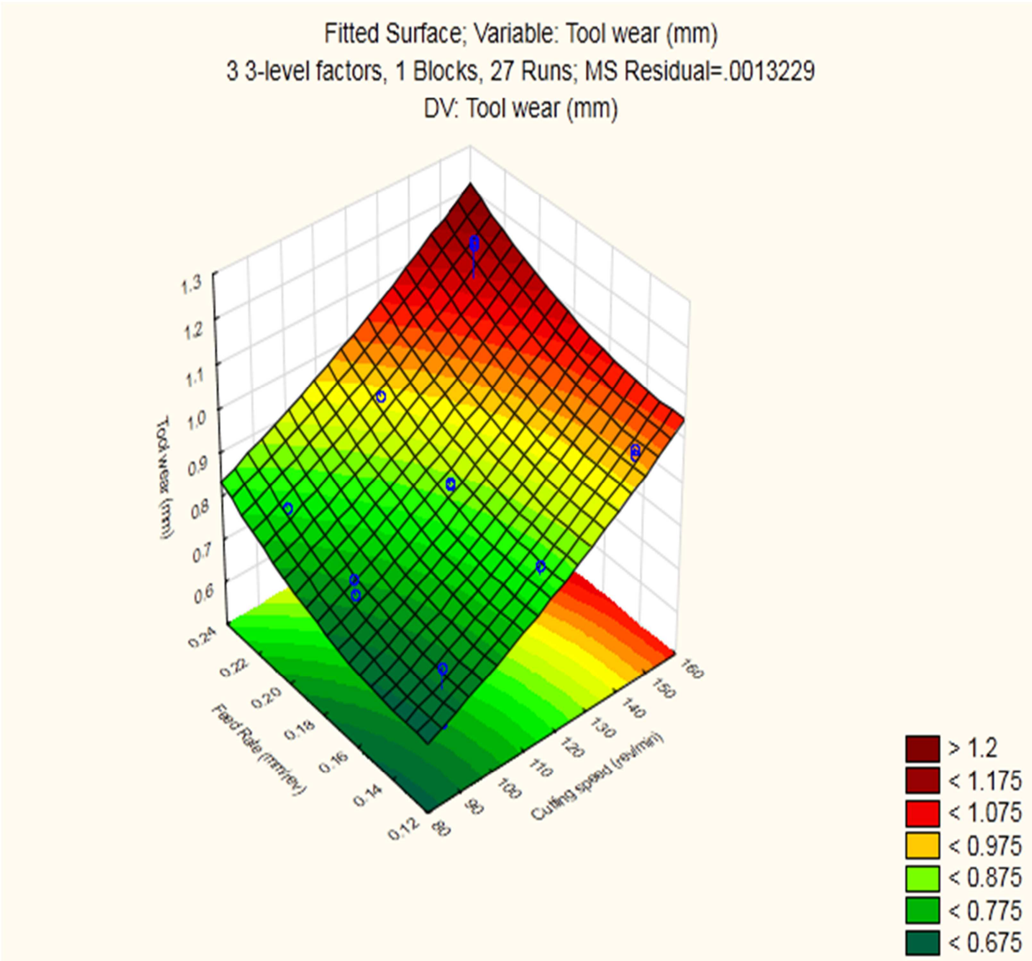

Figure 4.9: Response surface for cutting speed and feed rate on the tool wear

From the result obtained in the Table 4.2, the 3D graph was plotted using STATISTICA software with three different surface plots. A standard variable selection dialog will be displayed in which the variable for the x-, y- and z-axis were selected. From the analysis of variance done, the cutting speed and feed rate are the significant factor that leads most of the tool wears. The depth of cut is not significant and can be negligible when analysis the 3D surface response. From the 3D response surface, as the feed rate increase from 0.13 until 0.22 mm/rev, the tool wears increase substantially. When cutting speed increase from 90 to 150 rev/min, the tool wears increase significantly.

4.5 DISCUSSION

The experimental result agree with the finding of Yong Huang (2004) that cutting speed plays a dominant role in determining the tool performance in terms of tool life, followed by feed rate and depth of cut. After conducted the analysis of variance (ANOVA) with three different models, cutting speed and feed rate are highly significance with P-values less than 0.05. Depth of cut does affect the tool wear but it affects can be negligible.

From the 3D response surface in Figure 4.9, when the feed rate increase form 0.13 to 0.22 mm/rev and the cutting speed increase from 90 to 150 rev/min, the tool wears length observed become higher. This shows a good concurrence with statistical analysis of variance that indicated the cutting speed and feed rate are the significant factors in this study.

In addition, statistical analysis has investigated that there is a linear by linear interaction exist between the cutting speed and feed rate at 1*3 interaction (the “cutting speed component by feed rate component” interaction). A similar trend was observed when doing statistical analysis at linear by quadratic interaction.

This result has agreed to the study by Komanduri-Hou (2001) that reported because of friction between the tool and the machined surface, heat generated occurs at the cutting zone. This heat generation will then slowly reduce the strength of the tool and as number of turning increase in this study, the work piece surface will contact to the cutting tool more, the flank wear become more. Based on the research done by I. Ciftci (2006), as the cutting speed and feed rates are increased, the rubbing action also faster and more heat will be produced. This generated of heat will soften the edge of the cutting tool and wear occurred.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

In this chapter, all the main research points will be concluded and summarizes the observation from the resulting research. Wear of the cutting tool depends on the proper selection of cutting parameters. This present finding has study the effect of tool wear with dry machining with different depth of cut, feed rate and cutting speed. The resulting research gained were providing for the future research.

5.2 CONCLUSION

The study on turning process in dry condition of high carbon steel AISI 1065 with varying cutting speed, depth of cut and feed rate were performed. Experiment was planned with 3 levels Box-Behnken design was successfully implemented to study the effect of machining parameters to the tool wear. By STATISTICA, 27 experiments were done. An analysis of variance (ANOVA) was analyzed and it is found that cutting speed had the highest effect on the tool wear, feed rate had a moderate effect, and depth of cut had an insignificant effect.

The ANOVA analysis indicates that cutting speed and feed rate plays a dominant role in machining the AISI 1065. ANOVA analysis indicated that cutting speed and feed rate are highly significance with P-values less than 0.05. Besides, statistical analysis has investigated that there is a linear by linear interaction and linear by quadratic interaction exist between the cutting speed and feed rate at 1*3 interaction (the “cutting speed component by feed rate component” interaction).

The 3D surface response in Figure 4.8 shows that minimum tool wears is at the lowest cutting speed that is 90rev/min and at lowest feed rate 0.13mm/rev. As the depth of cut is not a significant factor in this study, the effects can be negligible in machining. When the depth of cut increase from 0.8 to 1.2 mm, the increase in tool wears length do not changes significantly. Conversely, if the cutting speed or the feed rate is increase, the increase in tool wear length will be greater than the increase in the depth of cut.

5.3 RECOMMENDATION

From this study, the relationship between the machining parameter is obtained. Depth of cut is not a significant factor in machining AISI 1065. For further study, the diameter of the work piece can be considered in the machining. As diameter of the work piece increase, the turning process can be done more and more flank wear can be seen clearly.

Beside that, as in this study the AISI 1065 are quenched in the water to harden the material. For future work, the AISI can be considered to quench in other medium such as oil or salt water for different hardness of the work pieces.

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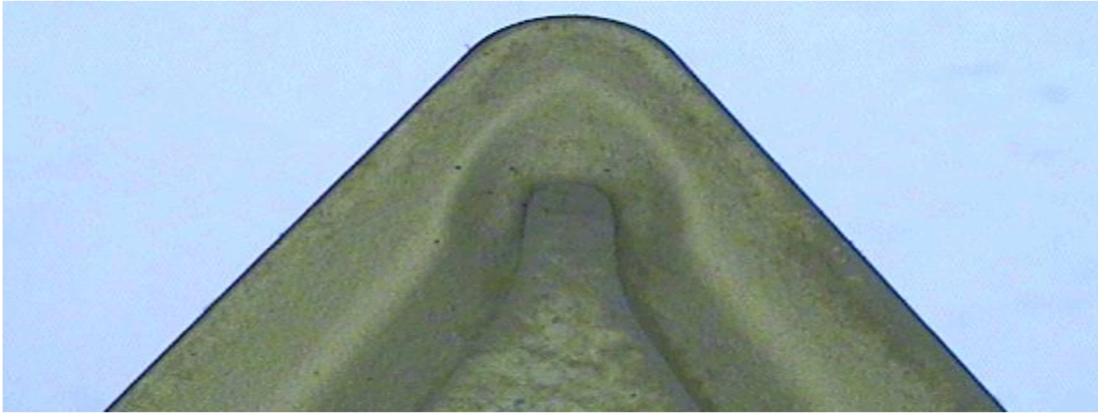
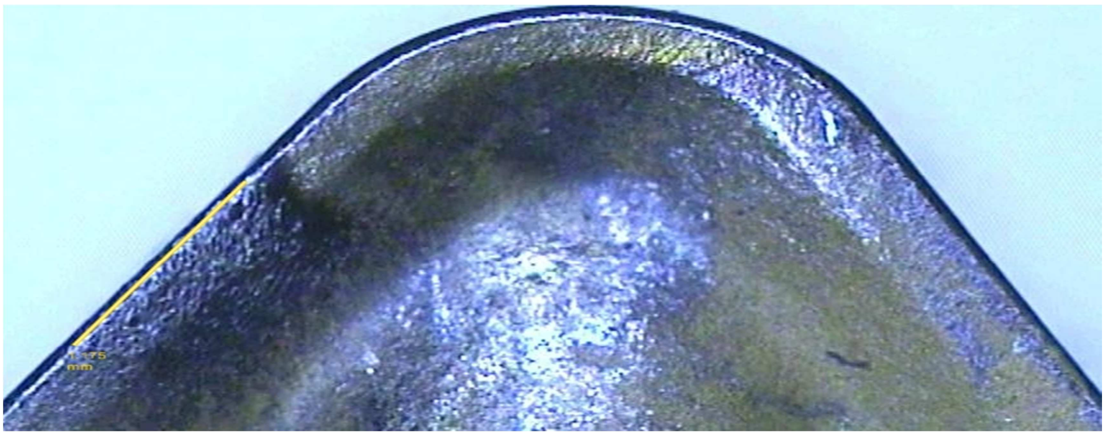
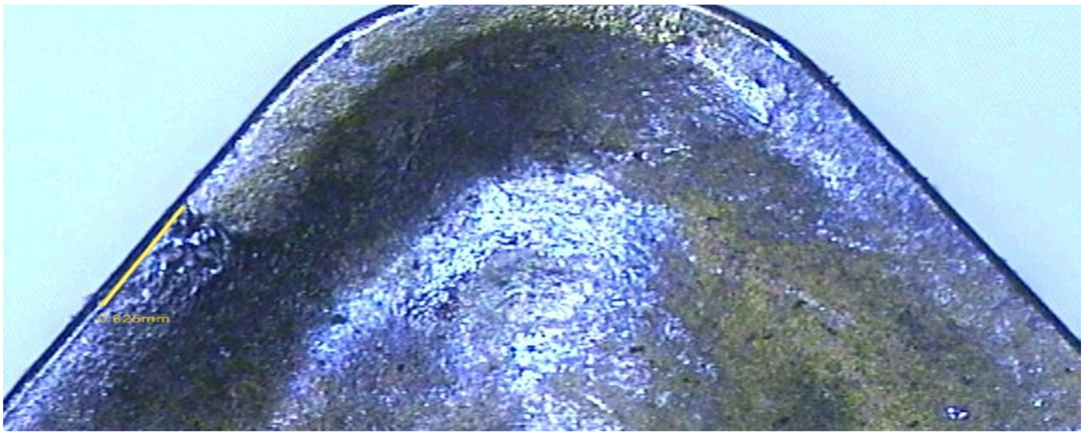
APPENDIX A



Coated carbide insert before turning



Highest wear length 1.175 mm at (V_c = 150m/min, Depth of cut = 1.0 mm and f = 0.22 mm/rev)



Shortest wear length 0.62 mm at (V_c = 90m/min, Depth of cut = 0.8 mm and f = 0.13 mm/rev)

APPENDIX B

FOUNDRY LABORATORY
FACULTY OF MECHANICAL ENGINEERING
UNIVERSITI MALAYSIA PAHANG

Chemical Results

Sample ID:

Material:

Customer:

Dimension:

Commision:

Filter metals:

Lab-no.:

Heat treatment:

Reference no.:

Heat-no:

Spectrometer Foundry-MASTER Grade :

	Fe	C	Si	Mn	P	S	Cr	Mo
1	98,0	0,690	0,226	0,619	< 0,0030	< 0,0030	0,151	0,0252
2	98,0	0,697	0,223	0,630	< 0,0030	< 0,0030	0,151	0,0195
3	98,1	0,613	0,212	0,621	< 0,0030	< 0,0030	0,151	0,0299
Ave	98,0	0,666	0,220	0,623	< 0,0030	< 0,0030	0,151	0,0249

	Ni	Al	Co	Cu	Nb	Ti	V	W
1	0,0333	0,0279	0,0076	0,128	< 0,0020	0,0051	< 0,0020	< 0,0150
2	0,0336	0,0285	0,0074	0,125	0,0030	0,0050	< 0,0020	< 0,0150
3	0,0381	0,0316	0,0079	0,131	< 0,0020	0,0037	< 0,0020	< 0,0150
Ave	0,0350	0,0293	0,0077	0,128	0,0022	0,0046	< 0,0020	< 0,0150

	Pb	Sn	B	Ca	Zr	As	Bi
1	< 0,0250	0,0069	< 0,0010	> 0,0010	0,0039	0,0072	< 0,0300
2	< 0,0250	0,0068	< 0,0010	> 0,0010	< 0,0020	0,0076	< 0,0300
3	< 0,0250	0,0069	< 0,0010	> 0,0010	0,0023	0,0085	< 0,0300
Ave	< 0,0250	0,0069	< 0,0010	> 0,0010	0,0023	0,0078	< 0,0300

Date:
21/02/2012

Test by:

Verify by:

Foundry Laboratory
Faculty of Mechanical Engineering
Universiti Malaysia Pahang
26600 Pekan, Pahang, MALAYSIA