RELATIONSHIP BETWEEN FAILURE MECHANISMS WITH PCBN TOOL

FATHUL NAIM BIN ABDUL JAMIL

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS ◆

JUDUL: **RELATIONSHIP BETWEEN FAILURE MECHANISMS WITH PCBN TOOL**

SESI PENGAJIAN: 2008/2009

Saya **FATHUL NAIM BIN ABDUL JAMIL (861121-02-5699)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda / ~~Sarjana / Doktor Falsafah~~)* ini disimpan di perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan)
√	**TIDAK TERHAD**	

Disahkan oleh:

____________________	____________________
(TANDATANGAN PENULIS)	(TANDATANGAN PENYELIA)
Alamat Tetap:	
NO 60 BLKG SEK KEB BOHOR **HUTAN KAMPUNG 05350** **ALOR STAR KEDAH**	**MAS AYU BINTI HASSAN** (Nama Penyelia)
Tarikh: **7 NOVEMBER 2008**	Tarikh: **7 NOBEMBER 2008**

CATATAN: * Potong yang tidak berkenaan

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

◆ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

RELATIONSHIP BETWEEN FAILURE MECHANISMS WITH PCBN TOOL

FATHUL NAIM BIN ABDUL JAMIL

Report submitted in partial fulfilment of the requirements for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2008

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project report and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering

Signature : __________________________________
Name of Supervisor : MADAM MAS AYU BINTI HASSAN
Position : Lecturer
Date : 7 November 2008

Signature : ____
Name of Pane : MR. MOHAMED REZA ZALANI BIN MOHAMED SUFFIAN
Position : Lecturer
Date: 7 November 2008

STUDENT'S DECLARATION

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

Signature	: ________________________________
Name	: FATHUL NAIM BIN ABDUL JAMIL
ID Number	: ME05020
Date	: 7 November 2008

DEDICATION

Special to my beloved mother and father

Abdul Jamil Bin Ahmad

Norhiza Binti Mohd Aroff

ACKNOWLEDGEMENTS

I feel grateful to Allah swt because this thesis has successfully completed in the given time. In this opportunity I would like to convey my full appreciation and thankful to my supervisor, Madam Mas Ayu Binti Hassan for her kindness on delivering me her knowledge on writing the thesis and lead me for encouragement, support, critics and advise to accomplish the objectives of my thesis. Besides that, I also would like to dedicate my special thanks to all assistant engineers in Faculty of Mechanical lab for their help and advice. Besides that, I also would like to express my gratitude to my fellow friends and to all my family members especially to my mum who have patient of love which enabled me to complete this work Less but not least, special appreciation to University Malaysia Pahang for their assistance in supplying relevant literatures and references materials.

ABSTRACT

Tool wear and eventual tool failure is a consequence of all machining operations and has been the subject of investigative research for the better part of the last century. The study of the tool wear is concern because tool wear adversely affects tool life, the quality of the machined surface and its dimensional accuracy, and consequently, the economics of cutting operations. The focus of this project is to study the relationship between failure mechanism of polycrystalline cubic boron nitrides (PCBN) with cutting parameters such as spindle speed, feed rate and depth of cut in the hard turning machining of hardened steel AISI 4340. All the images of tool wear will be taken using Image Analyzer in order to determine the severity of the wear occurred. The result is analyzed by using Design of Experiment (DOE) methodology with STATISTICA software. Lastly, it was also found that flank wear and crater wear is almost occurred in PCBN tool and spindle speed is the most important process variable associated with tool wear followed by feed rate and depth of cut.

ABSTRAK

Kehausan mata alat dan akhirnya membawa kepada kegagalan mata alat adalah akibat daripada proses operasi mesin dan telah menjadi salah satu subjek penyelidikan sejak sekian kurun lamanya. Pengkajian terhadap kehausan mata alat adalah sangat penting kerana ianya membawa kesan langsung kepada kegagalan mata alat, kualiti kepada produk dan ketepatan dimensinya, dan sudah pastinya kepada kadar ekonomi terhadap operasi pemesinan. Projek ini memfokuskan kepada penyelidikan hubungan di antara mekanisme kegagalan mata alat dengan menggunakan alat pemotongan *polycrystalline cubic boron nitride* dan juga pembolehubah seperti kelajuan gelendong, kadar suapan dan kedalaman pemotongan dengan menggunakan mesin larik dan keluli terkeras AISI 4340. Semua gambar kehausan mata alat diambil dengan menggunakan *Image Anayzer* untuk menentukan kepelbagaian kehausan yg berlaku. Hasil keputusan eksperimen dianalisis dengan menggunakan kaedah *Design of Experiment (DOE)* dan perisian *STATISTICA.* Akhir sekali, daripada hasil eksperimen didapati *flank wear* dan *crater wear* yang selalu terhasil daripada pemesinan dengan menggunakan mata alat PCBN dan kelajuan gelendong merupakan pembolehubah yang sangat penting dalam memberi kesan terhadap kehausan mata alat diikuti oleh kadar suapan dan kedalaman pemotongan.

LIST OF SYMBOLS

N	Spindle speed
f	Feed rate
d	Depth of cut
mm	Millimeters

LIST OF ABBREVIATIONS

PCBN	Polycrystalline cubic boron nitride
CBN	Cubic boron nitride
AISI	American Iron and Steel Institute
DOE	Design of experiment
ANOVA	Analysis of variance
SEM	Scanning electron microscope
RPM	Revolution per minutes
HSS	High speed steel
EPMA	Electron probe microanalysis
ppm	Parts per million
SS	Statistical significant
MS	Mean square

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In general, eventual tool wear is tool failure. Tool wear plays a vital role in influencing both the ease of cutting and the quality of the resultant machined surface [1]. There has been a significant amount of research dedicated to understanding the failure mechanism of the cutting tool. One of the factors that influence the failure of the cutting tool is depending on the tool behaviour. Tool behaviour is influenced by many factors which include the composition of the tool material, the steel workpiece, the nature of cutting operation, the cutting conditions and the tool geometry.

There are several wear of the cutting tool that occurs during hard turning process. The mechanism most commonly used to explain the wear of tools includes cracking and chipping, abrasion, adhesion, diffusion and chemical wear. All of the wear can be observe by using scanning electron microscope (SEM) or optical microscope. This paper presents an experimental study of hard turning with polycrystalline cubic boron nitride (PCBN) tools to investigate the relationship between PCBN tools with failure mechanism that will be occurred in different cutting speed, feed rate, and depth of cut.

1.2 OBJECTIVES

i) To investigate relationship between failure mechanisms with polycrystalline cubic boron nitride (PCBN) tools in turning process.
ii) To study the effect of machining parameters such as cutting speed, feed rate and depth of cut in PCBN tool.
iii) To recommend the optimum parameter for finishing cutting conditions of PCBN tools.

1.3 PROJECT SCOPES

i) Failure mechanism in polycrystalline cubic boron nitride (PCBN) tools using conventional lathe machine when machining hardened steel AISI 4340 of 60 HRC.
ii) Conduct the experiment at different spindle speed, feed rate and depth of cut.
iv) DOE methodology is applied to define the main parameters and relationship between parameters.
v) The wear of PCBN tools occurred is examined using optical microscope.

1.4 PROBLEM STATEMENT

Hardened steel parts are widely used in the automotive, gear, bearing, tool, and die industry. A recent study reports that the automotive industry increasingly using hard turning more than grinding gear-stem machine. So that they can eliminate the need of grinding parts for finishing. By eliminating this process, the automotive industry reduced capital out-lays by as much as 40% and increased production by approximately 30% [2]. One major problem in turning the hardened steels is the tool wear caused by the hardness of the material. Polycrystalline cubic boron nitride (PCBN) cutting tools have found widely acceptance in machining a variety of hard materials [3]. Thus, the study of tool wear and the damage caused to the cutting tool in PCBN is quite important in order to reduce wear rate so that it will suitable for precision applications and offer better performance improvements.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION OF WEAR

Wear has great technological and economic signifificance because it changes the shapes of tools and consequently, affects the tool life, tool size, and quality of the parts produced [4]. The importance of wear is evident in the number of parts and components that continually have to be replaced or repaired. In addition, tool wear plays a vital role in influencing both the ease of cutting and the quality of the resultant machined surface. The major types of wear encounted in manufacturing operations are described next.

2.1.1 Adhesive wear

Adhesion occurs when material from the workpiece or chip melts due to high temperature and stress conditions at the cutting edge and adheres to the non-contact surfaces of the tool [5]. Fig. 2.1 shows a tangential force is applied to the model, shearing can take place either (a) at the original interface or (b) along a path below or above the interface. Because of factors such as strain hardening at the asperity contact, diffusion, and mutual solid solubility, the adhesive bonds often are stronger than the base metals. Thus, during sliding, fracture usually follows a path in the weaker or softer component; this is how a wear fragment is generated. Although this fragment is attached to the harder component (upper surface in Fig 2.1c), it eventually becomes detached during further rubbing at the interface and develops into a loose wear particle. This process is known as adhesive wear or sliding wears [4].

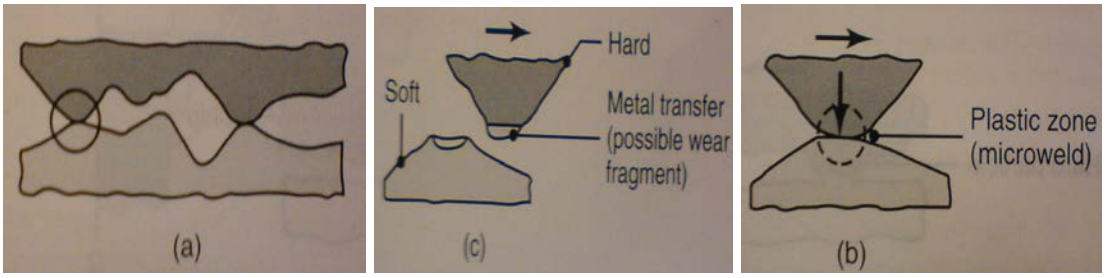


Figure 2.1: Schematic illustration of (a) two contacting asperities, (b) adhesion between two asperities, and (c) the formation of a wear particle [4].

Adhesive wear can be reduced by the following methods:

a) Selecting materials that do not form strong adhesive bonds.
b) Using a harder material as one of the pair.
c) Using materials that oxidize more easily.
d) Applying hard coatings that serve methods a to c above. Coating one surface with a soft material (such as tin, silver, lead, or cadmium) also is effective in reducing wear.

2.1.2 Abrasive wear

This type of wear is caused by a hard, rough surface (or a surface containing hard, protruding particles) sliding across another surface. As a result, microchips or silver are produced, thereby leaving grooves or scratches on the softer surface (Fig. 2.2).

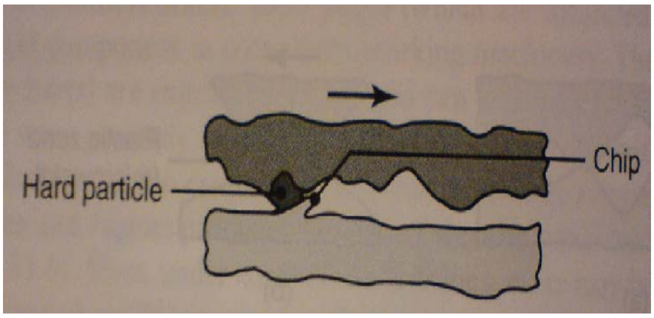


Figure 2.2: Schematic illustration of abrasive wear in sliding. Longitudinal scratches on a surface usually indicate abrasive wear [4].

The abrasive wear resistance of pure metals and ceramics has been found to be directly proportional to their hardness. Thus, abrasive wear can be reduced by increasing the hardness of materials (usually by heat treating) or by reducing the normal load [4].

2.1.3 Corrosive wear

This type of wear is caused by chemical or electrochemical reactions between the surfaces and the environment. This wear is also known as oxidation or chemical wear. The fine corrosive products on the surface constitute the wear particle in this type of wear. When the corrosive layer is destroyed or removes through sliding or abrasion, another layer begins to form, and the process of removal and corrosive layer formation is repeated [4]. Corrosive wear can be reduced by:

- Selecting materials that will resist environmental attack.
- Controlling the environment.
- Reducing operating temperatures to lower the rate of chemical reaction.

2.1.4 Fatigue wear

Fatigue wear (also called surface fatigue or surface-fracture wear) is caused when the surface of a material is subjected to cyclic loading. The wear particles usually are formed through spalling or pitting. Another type of fatigue wear is by thermal fatigue. Cracks on the surface are generated by thermal stresses from thermal cycling, such as when a cool die repeatedly contact hot workpiece (heat checking). These cracks then join, and the surface begins to spall, producing fatigue wear [4]. Fatigue wear can be reduced by:

- Lowering contact stresses.
- Reducing thermal cycling.
- Improving the quality of materials by removing impurities, inclusions, and various other flaws that may act as local points far crack initiation.

2.1.5 Other types of wear

Several other types of wear can be seen in manufacturing operations.

- Erosion is caused by loose abrasive particles abrading a surface.
- Fretting corrosion occurs at interfaces that are subjected to very small reciprocal movements.
- Impact wear is the removal (by impacting particles) of small amounts of material from a surface.

2.2 PCBN TOOL MATERIAL

Next to diamond, cubic boron nitride (cBN), primarily polycrystalline cubic boron nitride (PCBN) is the hardest material presently available. Introduced in 1962 under the trade name Borazon, cubic boron nitride is made by bonding a 0.5 to 1 mm layer of polycrystalline cubic boron nitride to a carbide substrate by sintering under high pressure and high temperature. While the carbide provides shock resistance, the cBN layer provides very high wear resistance and cutting-edge strength. At elevated temperatures, cBN is chemically inert to iron and nickel (hence no wear due to diffusion). Its resistance to oxidation is high and, thus, is particularly suitable for cutting hardened ferrous and high-temperature alloys [4].

2.3 PCBN cutting tool wear

PCBN tool wear is most often discussed in terms of flank and crater wear. Traditionally, tool life is defined by flank wear due to the significant influence this parameter has on the surface finish and dimensional accuracy of the machined part. Crater wear has a strong influence on process reliability as it can lead to instantaneous failure due to chipping or fracture of the tool edge Fig. 2.3 [6]. The mechanisms most commonly used to explain the wear of PCBN tools include abrasion, adhesion, diffusion and chemical wear [7]. A review of the available literature of the PCBN tool wear mechanisms will be discused next.

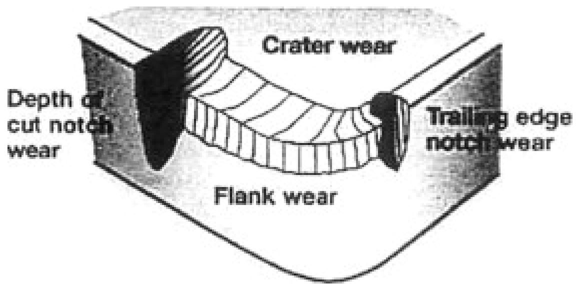


Figure 2.3: Typical wear types observed on cutting tools [6].

2.4 PCBN TOOL WEAR MECHANISM

2.4.1 Abrasion

Some of the earliest research on tool wear, by Narutaki and Yamane [8], identified the workpiece material as having a strong influence on the wear of PCBN cutting tools. They found that the composition of the workpiece and to a lesser extent, the hardness, greatly influenced tool life. The performance of high and low CBN content materials on different steel types was evaluated. The high CBN content material with a metal binder gave the longest tool life in machining high speed steel (HSS) which is extremely abrasive due to the presence of very large carbides. This ranking was reversed for tool steels, which are less abrasive and on case-hardened steels, with the low CBN content material giving the best performance. They also reported decreasing tool wear rate and cutting temperature with increasing hardness for workpiece hardness values above 40HRC. Later experiments by Luo et al. [5] found that this trend continued up to 50HRC after which the wear rate increased.

Konig et al. [9] confirmed the effect of workpiece composition on tool life and related PCBN tool performance to the size, type and composition of the carbide phases and the percentage of martensite in the steel. Machining tests on different case-hardened, through hardened and tool steels, all at the same hardness (55HRC) found that the lowest tool life was obtained on the tool steels due to their high carbide content. These tests also showed that for the steels with a primarily martensitic matrix, tool wear rate increased with increasing martensite content. A grooved surface was observed on the flank of the tools after machining. The authors reported a correlation between the size of the primary carbides (when they were present) and the size of the grooves, and in the case of the martensitic steel, the grooves may be linked to the martensite grains. Carbides were determined to be more abrasive than martensite as the resultant grooves are deeper.

Luo et al. [5] examined the behaviour of a PCBN material with a ceramic based binder ($TiC+Al_2O_3$) in turning hardened AISI4340 alloy steel. They proposed that the main wear mechanism for PCBN is abrasion of the binder by hard particles in the workpiece. SEM examination of the tools showed the presence of grooves on the tool flank, which is typical of abrasive wear. It is suggested that the binder of the tool is abraded by hard particles of the workpiece material, which leads to CBN grains being detached from the bond.

2.4.2 Diffusion and adhesion

Diffusion is made possible by the high temperatures reached during the metal cutting process [10]. The binder in PCBN cutting tools is reported to be most susceptible to this form of wear and some of the phases react quite readily with the workpiece material, resulting in structural changes [10]. This can make the binder less wear resistant and lead to an increase in abrasive wear.

The work by Narutaki and Yamane [8] included an investigation of the chemical interactions between the tool and the workpiece. Diffusion was not observed between CBN grains and pure iron. In tests with ceramic binder PCBN material and carbon steel, boron diffused into the steel and the concentration in the PCBN was depleted to a depth of 50 mm. This depletion was not obvious from examination of the microstructure and was not detected by Electron probe microanalysis (EPMA) and it is thought that the grain boundaries are the boron source rather than the CBN grains. In the case of metal binder PCBN material, cobalt was observed to diffuse from the tool but only from a depth of 10 mm or less. The rate of diffusion was found to increase with increasing temperature but the authors [8] concluded that since that the cutting temperature with PCBN is relatively low, measured to be less than 900 1C, this wear mechanism is only considered significant when extremely severe cutting conditions are used.

Farhat [11] investigated PCBN tool wear when machining P20 mould steel at cutting speeds of 240, 600 and 1000m/min. At all three speeds, iron deposits were present on the flank and rake faces of the tools and also present on the surface of the crater at 600 and 1000m/min. Here, it is proposed that the steel workpiece melts in the area of contact with the tool due to the high temperatures there and is then expelled and deposited on the non-contact surfaces of the tool.

In addition, after machining at 1000 m/min there is a Mn and Cr rich layer evident on the tool flank, close to the cutting edge, which is attributed to the extremely high cutting temperatures generated. At these temperatures, B and N in the tool material dissociate and diffuse into the molten Fe present in the contact area and are subsequently deposited on the tool surfaces. The Mn and Cr rich layer is thought to be formed due to reaction between the workpiece and the PCBN tool material, which reduces the strength of the tool. This layer is not formed at the lower cutting speeds because the required high temperature is not generated.

2.4.3 Built up layer (chemical reaction)

Similar to diffusion, the high temperatures at the cutting edge promote chemical reactions in that area. The built up layer which is frequently observed on PCBN tools after metal cutting is due to a chemical reaction occurring in the contact zone between the workpiece and the tool or the atmosphere [5]. There is general consensus that a chemical reaction occurs between the tool and the workpiece in the area of contact, which is facilitated by the high temperature conditions. Due to the relatively high forces, the products of this reaction are expelled into the surrounding area and deposited on the tool surfaces. The area and thickness of the layer that is deposited depends on the cutting conditions and the tool wear rate as these factors determine the temperature in the contact zone.

Analyisis of the layer deposited in the experiments performed by Klimenko et al. [12] found evidence of a range of elements found in the tool and the workpiece (B, C, N, Si, Al, Cr, Fe) and products of their reaction with atmospheric oxygen. The layer generated in the machining test by Luo et al. [5] also contains elements from both the workpiece (Fe, Ni, Mn) and the binder of the CBN tool (Al and Ti).

König and Neises [10] reported the presence of layers consisting primarily of aluminium at the borders of the contact zone. As Al is present only in parts per million (ppm) in the 100Cr6 workpiece, this is not thought to be the source of the deposited layer. It is suggested that the chip may remove Al from the binder of the PCBN and deposited on the tool surfaces.

A conclusion reached by many of the researchers is that the compounds formed by the chemical reaction in the contact zone are not as hard as the PCBN tool material, and are therefore more easily abraded. The structure and composition of the adhered layer are determined by the PCBN material. Chou et al. [13] reported that the layer on low CBN material is uniform and smooth with a flake-like structure and some grooves present at the highest cutting speeds. On high CBN material the layer is rough and grooved. This feature becomes more pronounced as the cutting speed increases and the thickness also increases. The layer on the high CBN material was much more difficult to remove. SEM examination of the tools following removal of the transferred layer found that on the low CBN material there is a smooth surface on the CBN grains and shallow pockets where grains have been pulled out. This is attributed to adhesive wear, after which fine scale attrition dominates the wear because of the strong bond between the CBN and the ceramic binder. There is a grooved surface on the high CBN tool. It is suggested that bond failure between the CBN and the binder matrix results in the CBN grains being pulled out. The grooves may be caused by abrasion by the pulled- out CBN grains and hard particles in the workpiece.

In contradiction to this theory, there is also evidence that the BUL can protect the tool from wear. Luo et al. [5] found that PCBN tool life increased with increasing cutting speed until a critical value was reached after which tool life decreased. It is suggested that the adhered layer protects the tool until a temperature is reached at which the layer becomes soft and is removed and tool wear rate then increases. During examination of worn tools, Barry and Byrne **[**14**]** found that the CBN grains had suffered more wear than the binder phase leading the leading the authors to conclude that the BN and certain work material inclusions react, forming products which offer protection to the TiC ceramic phase against diffusion/dissolution wear.

Klimenko et al. [12] suggested that the formation of a liquid phase in the contact zone could be used to explain the low coefficient of friction when machining with PCBN. It was also noted that the presence of the layer on the tool surfaces can affect the dissipation of heat and hence the cutting temperature.

2.5 TURNING PROCESS

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material. The turning process requires a turning machine or lathe, workpiece, fixture, and cutting tool. The workpiece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine, although some operations make use of multi-point tools. The cutting tool feeds into the rotating workpiece and cuts away material in the form of small chips to create the desired shape. Turning is used to produce rotational, typically axi-symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces. Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom designed shafts and fasteners. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed **[**15**]**.

As shown in figure 2.4, turning is performed at various rotational speeds, *N*, of the workpiece clamped in a spindle, depths of cut, *d*, and feeds, *f*, depending on the workpiece materials, cutting tool materials, surface finish and dimensional accuracy required, and the characteristics of the machine tool [4].

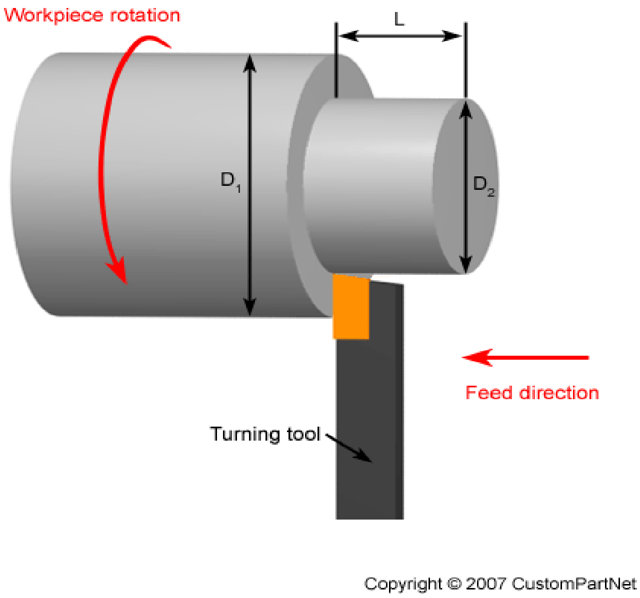


Figure 2.4: Schematic illustration of the basic turning operation **[**15**]**

A review from literature shows that hard turning makes a major contribution to search flexibility during the machining of hard alloys or high mechanical strength materials. In fact, intermediate operations such as grinding operations can be eliminated. This, in most cases leads to substantial cost reduction in manufacturing, and therefore hard turning operations are developing wide applications in industry **[**16**]**. Moreover, the cutting can be performed without coolant and therefore the process provides an added advantage from the ecological point of view **[**17**]**.

2.5.1 Cutting parameters

In turning, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based upon the workpiece material, tool material, tool size, and more.

2.5.2 Cutting speed

Cutting speed is defined as the speed at which the work moves with respect to the tool, usually measured in revolution per minute [4]. It is used to express the velocity of the tool as it cuts a specific material. Each material has an optimum range of cutting speed. It is also determined primarily by the machinability of the material and the hardness of the cutting tool.

2.5.3 Spindle speed

The rotational speed of the spindle and the workpiece in revolutions per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the workpiece where the cut is being made. In order to maintain a constant cutting speed, the spindle speed must vary based on the diameter of the cut. If the spindle speed is held constant, then the cutting speed will vary [15].

2.5.4 Cutting feed

The distance that the cutting tool or workpiece advances during one revolution of the spindle, measured in millimetre per revolution. In some operations the tool feeds into the workpiece and in others the workpiece feeds into the tool [15].

2.5.5 Feed rate

The speed of the cutting tool's movement relative to the workpiece as the tool makes cut. The feed rate is measured in millimetre per minutes and is the product of the cutting feed and the spindle speed [4].

2.5.6 Depth of cuts

The depth of cut may be defined as the depth of the chip taken by the cutting tool and is one-half the total amount removed from the workpiece in one cut [15]. Figure 5 is shows the relationship between initial diameter and final diameter. Depth of cut is typically measured in millimeters or inches. Cutting speed and depth of cut significantly influence tool life. Increased cutting speed and depth of cut result in increased temperatures at the cutting zone.

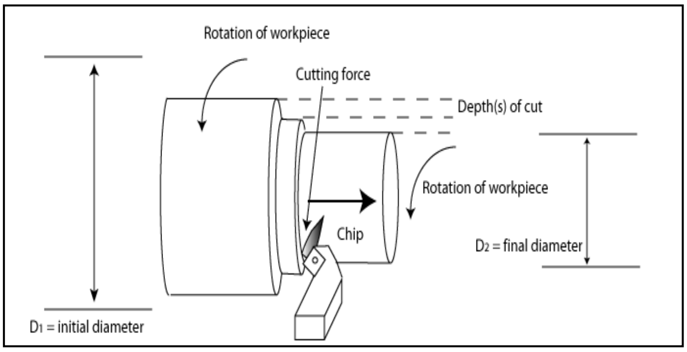


Figure 2.5: The relationship between initial diameter and final diameter [4]

It is calculated as follows:

$$DOC = \frac{D_1 - D_2}{2} \tag{2.1}$$

2.5.7 Cutting time

The time required for the cutting tool to make all the necessary cuts in the workpiece for each operation. The cut time for any given operation is calculated by dividing the total cut length for that operation by the feed rate, which is the speed of the tool relative to the workpiece [4]. It is calculated as follows:

$$t = \frac{\text{length}}{\text{feed x spindle speed}} \tag{2.2}$$

The cutting time does not include the time required for tool approach and retraction. Because the time spent in noncutting cycles of a machining operation is unproductive and adversely affects the overall economics, the time involve in approaching and retracting tools to and from the workpiece is an important consideration. Machine tools are designed and built to minimize this time. One method of accomplishing this is to rapidly traverse the tools during noncutting cycles followed by a slower movement as the tool engages the workpiece [4].

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter will describe about the overall process methodology in this project from beginning until the end of this project. There are 4 main processes that start with experimental, collecting the data, analysis the result and lastly confirmation test. Those processes will be described in this chapter according to the flowchart. In this part, every data and information will be gathered together and concluded according to the objective and scope of this project.

The methods are basically refers to the design of experiment (DOE) methodology and its procedure. The design of experiment (DOE) is not a simple one-step process but actually a series which must follow certain sequence for the experiment to yield an improve understanding of product or process performance.

3.2 FLOW CHART

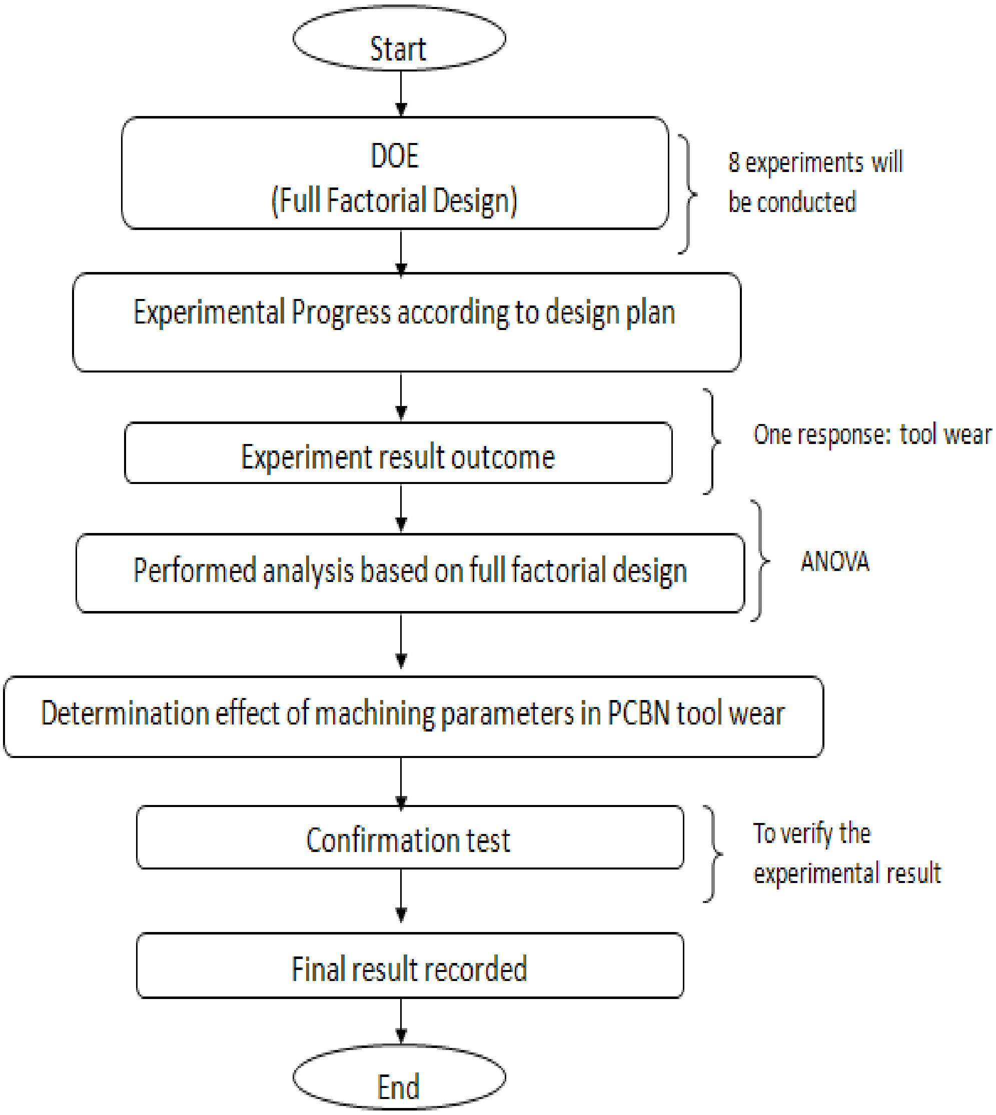


Figure 3.1: Flow chart outlining the analysis steps undertaken

3.3 EXPERIMENTAL SETUP

3.3.1 Workpiece material

AISI 4340 is chosen as the workpiece material because it is one of the types of hardened steel and it is recommended by most of journal in cutting with PCBN tool [20]. The material workpiece is a cylindrical section with a diameter of 60 mm and length of 200 mm. Table 3.1 shows the chemical composition of the material [20].

Table 3.1: Chemical composition of AISI 4340 [20]

AISI	C	Mn	P, max	S, max	Nb	Ni	Cr	Mo	W
4340	0.43	0.83	0.025	0.02	7.8	1.71	0.79	0.25	0.55

3.3.2 Cutting tool

The cutting tool used in this experiment is inserts polycrystalline cubic boron nitride (PCBN). The properties of the PCBN cutting tool material are listed in table 3.2 [16].

Table 3.2: Properties of the PCBN cutting tool material [16]

Density (g/cm^3)	Hardness (HV_{10})	Toughness ($MPa\ m^{1/2}$)	Elastic modulus (GPa)	Thermal conductivity (W/mK)
4,3	~4000	4,2	587	45

3.3.3 Machine Tool

The machine tool used in this experiment for turning process is conventional lathe machine. The picture of the conventional lathe machine is shown in figure 6.

Figure 3.2: Conventional lathe machine

3.4 DESIGN OF EXPERIMENT

In identifying the effets of machining parameters in PCBN tool wear, the Design of Experiment (DOE) is use so that the possible effect of the variables during machining process can be determined. This method also can develop experiment a ranges from uncontrollable factor, which will be introduced randomly to carefully controlled parameters. The factor must be either quantitative or qualitative. Must decide the range of value for quantitative factors on how they are going to be measured and the level at which they will be controlled during this experiment. In the meantime, the qualitative factors are parameters that will be determined unconnectedly [19].

This method has found wide application in many orders activities [19], where new products are produced and the some improvement in that production. Some applications of experimental design in engineering design are comprise, evaluation and comparison of basic design parameter, hence the product will work under a wide variety of machining conditions and finally is determination of the solution of design parameters that affect product performance [19].

3.5 DETAIL EXPERIMENTAL DESIGN

Based on Design of Experiment (DOE), the full factorial design experiment will be applied as a tool for design of experiment and data analysis. This section will provide with the detail of (DOE) which is the full factorial experiment design method and the variables that must be considered for this investigation.

3.5.1 Variables

Machining parameters and machining characteristics are the two groups of variables that will be studied. Machining parameters are classified as all the data or source that belongs to such machines involve for this study. Machining parameters as the independent variables that involved in this investigation are spindle speed (*N*), feed rate (*f*) and depth of cut (*d*). The Machining characteristics are the dependent variables in this study are tool wear.

3.5.2 Machining parameters

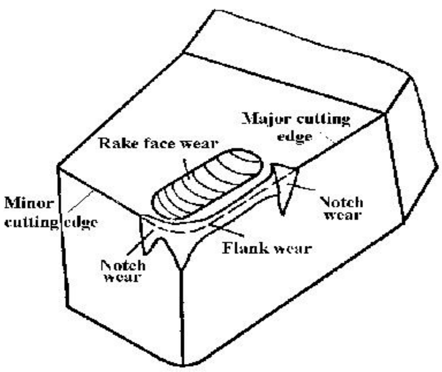
Based on previous literature study, there are some factors are significant in influenced the tool wear. The factors are properties of tool and workpiece materials, tool geometry, process parameters, cutting fluids, and many other parameters of the machining system. This study will be focused on the machining parameter influenced in tool wear. The setting of the machining parameters for finishing cutting condition is given in table 3.3 based on recommended in journal [20] and manual operations of lathe machine.

Table 3.3: The design machining parameters and their levels

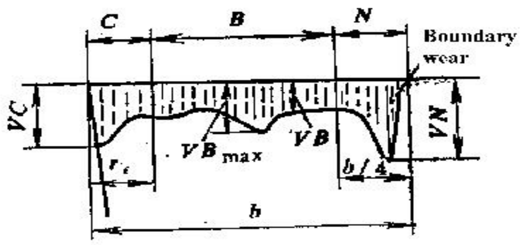
Machining parameters	Level	
	1	**2**
Spindle Speed, *N* (RPM)	909	1305
Feed rate, f (mm/rev)	0.1	0.18
Depth of cut, *d* (mm)	0.5	1.0

3.5.3 Machining conditions and characteristic

In this study, all the cutting tests were performed without coolant with the tool wear is measured after 80 mm of cutting path. The machining characteristics that will be investigated are tool wear. Because of the PCBN tool wear is discussed more on the flank wear, so the length of the flank wear occurred is measured by using scanning electron microscope (SEM) or image analyzer. The unit for flank wear (VB_{max}) is measured in millimeter but also depends on the magnifier of lens in image analyzer. The pictures of flank wear are shown in figure 3.2 (a) and (b) while picture for image analyzer is shown in figure 3.3.



(a)



(b)

Figure 3.3: (a) Types of tool wear on turning tools. (b) Length of flank wears (*VBmax*)

Figure 3.4: Image Analyzer

3.5.4 Full Factorial Design

The full factorial designs are among the most widely DOE used for product, process design and process improvement [19]. The capability to estimate the correlation between two or more factor in one time is the one of the advantages when used Full Factorial design method. In addition, this method also can identify the importance factors in the experiment under variety of conditions without sacrifices any factors [19].

The very simple type of factorial design is a two-factor experiment, which is the effect of two factors on one or more response variables are tested all together. It is commonly use two level design for each factor study, where k is the number of combinations will be 2^k. The two level design can only yield information on the edges and by doing so, it provides simple linear model that accounts for all possible parameter relations [19].

In this study, three-factor experiment design will be in used with two-level full factorial design experiment. The number of experiment required is 2^3 equal to 8 experiments. The table of full factorial experimental design is shown in table 3.4.

Table 3.4: Table of full factorial experimental design

No. of experiment	Factors			Tool wear (mm)
	Spindle speed, *N* (RPM)	**Feed rate, *f* (mm/rev)**	**Depth of cut, *d* (mm)**	
1	909	0.1	0.5	
2	909	0.1	1.0	
3	909	0.18	0.5	
4	909	0.18	1.0	
5	1305	0.1	0.5	
6	1305	0.1	1.0	
7	1305	0.18	0.5	
8	1305	0.18	1.0	

Analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of experiment to determine the percentage contribution of each factor. ANOVA was carried out to find the dependent variables that effect the machining parameters and machining characteristics by using STATISTICA software. The software will then calculate the relations of three factors to responses supported by ANOVA.

3.6 CONFIRMATION TEST

The confirmation test must be run to verify the conclusion from previous activities of the experimentation. Confirmation test is very important step in full factorial design because it as the direct proof of the methodology. After the values of main effect from the independent variables are known, one trial of confirmation test was done by using minimum value of main effects of tool wear by using lathe machine. After that, the value of wear predicting from the ANOVA was compared with the result of the confirmation test that have been done. In DOE, error margin for confirmation should be less than 10%.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The investigation of tool wear of PCBN tool was successfully analysis have been carried out to evaluate the machine parameters. The results of the analysis will be shown in this following section.

The results of the experimentation are analyzed by using STATISTICA software. The result are interpret base on the data, tables, and graft. The analysis consists of 3 main elements which are:

i. Main Effects: Tool wear, mm
ii. Analysis of Variance (ANOVA)
iii. Estimated result at Optimum condition

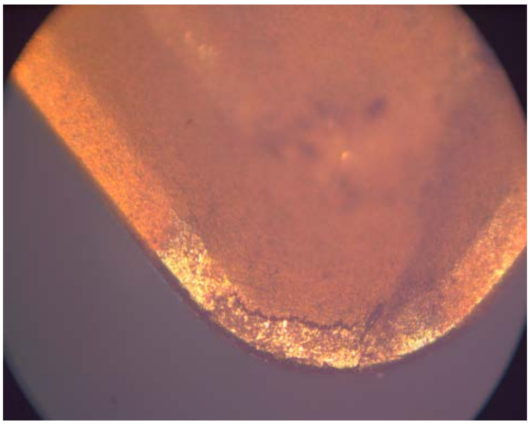
These three elements will give us significance of each parameter to the performance of machining characteristics and their optimum condition.

Besides the results of the statistical analysis, the result of the confirmation test is also discussed in this chapter.

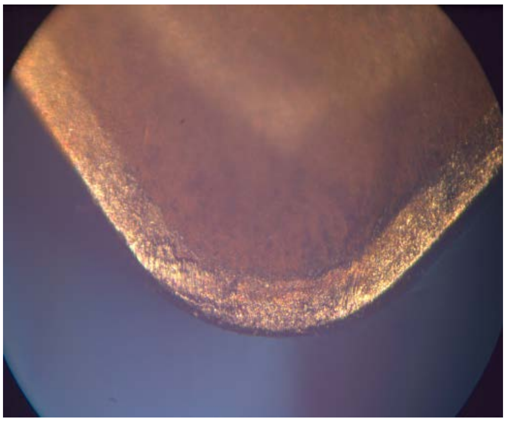
4.2 Results 2^3 Full Factorial Experiments response to Tool Wear, mm.

Figure 4.1 shows the image result of PCBN tool wear after machining with conventional lathe machine using Image Analyzer with magnification 10x lenses. The total results of experimentation are recorded and generated in the Design of Experiment (DOE) table using STATISTICA software.

Table 4.1 presents the data from the 8 runs of 2^3 Design of Experiment which is involved the factors spindle speed (RPM), feed rate (mm/rev), and depth of cut (mm) as an independent variables and tool wear (mm) as a dependent variables.

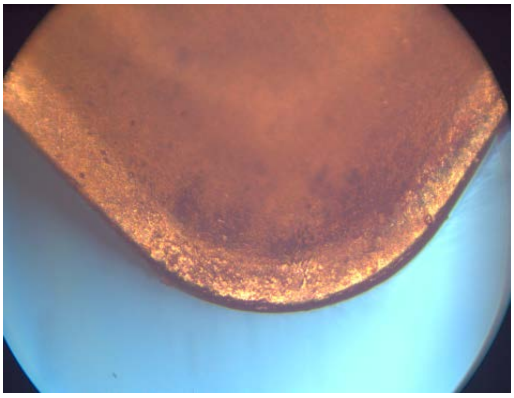


Experiment 1

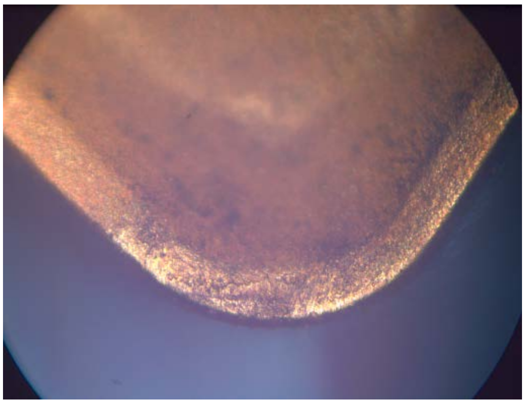
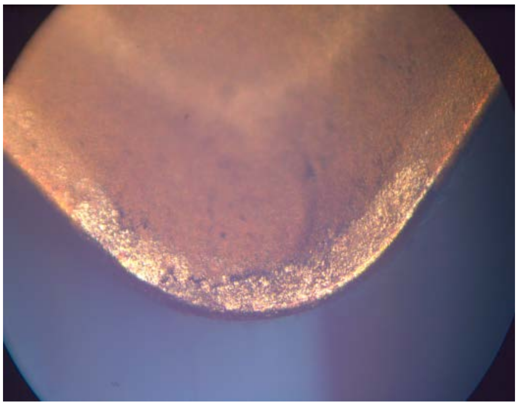


Experiment 2

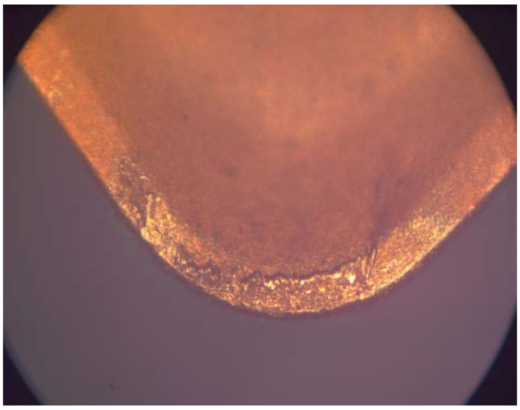
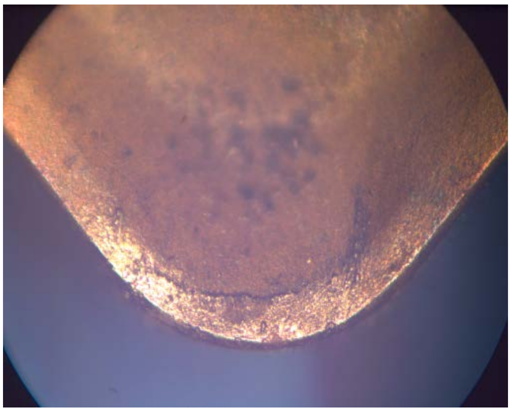
Experiment 3



Experiment 4

Experiment 5 | Experiment 6

Experiment 7 | Experiment 8

Figure 4.1: Image of tool wear taken by using image analyzer with magnification 10x lenses

Table 4.1: Result of tool wear for 2^3 Design of Experiment

No of experiment	Design: 2**(3-0) design (cutting tool wear result.sta)			
	1 Spindle Speed, N (RPM)	2 Feed Rate, f (mm/rev)	3 Depth of Cut, d (mm)	4 Wear Dimension (mm)
1	990	0.10	0.5	0.1874
2	990	0.10	1.0	0.1887
3	990	0.18	0.5	0.1941
4	990	0.18	1.0	0.1982
5	1305	0.10	0.5	0.1989
6	1305	0.10	1.0	0.1992
7	1305	0.18	0.5	0.2036
8	1305	0.18	1.0	0.2139

4.3 Main Effects

The significant of effect is important in determination of optimum condition. Table 4.2 gives the significant factor from this investigation. The parameters such spindle speed and feed rate (red font) as the main effect which contributes more effect of tool wear in cutting process.

Table 4.2: Significant factor of this study

Factor	Effect Estimates; Var.:Wear Dimension (mm) 2**(3-0) design					
	Effect	Std.Err.	t(4)	p	Coeff.	Std.Err. Coeff.
Mean/Interc.	0.198000	0.000994	199.1862	0.000000	0.198000	0.000994
(1)Spindle Speed, N (RPM)	0.011800	0.001988	5.9353	0.004040	0.005900	0.000994
(2)Feed Rate, f (mm/rev)	0.008900	0.001988	4.4767	0.011018	0.004450	0.000994
(3)Depth of Cut, d (mm)	0.004000	0.001988	2.0120	0.114540	0.002000	0.000994

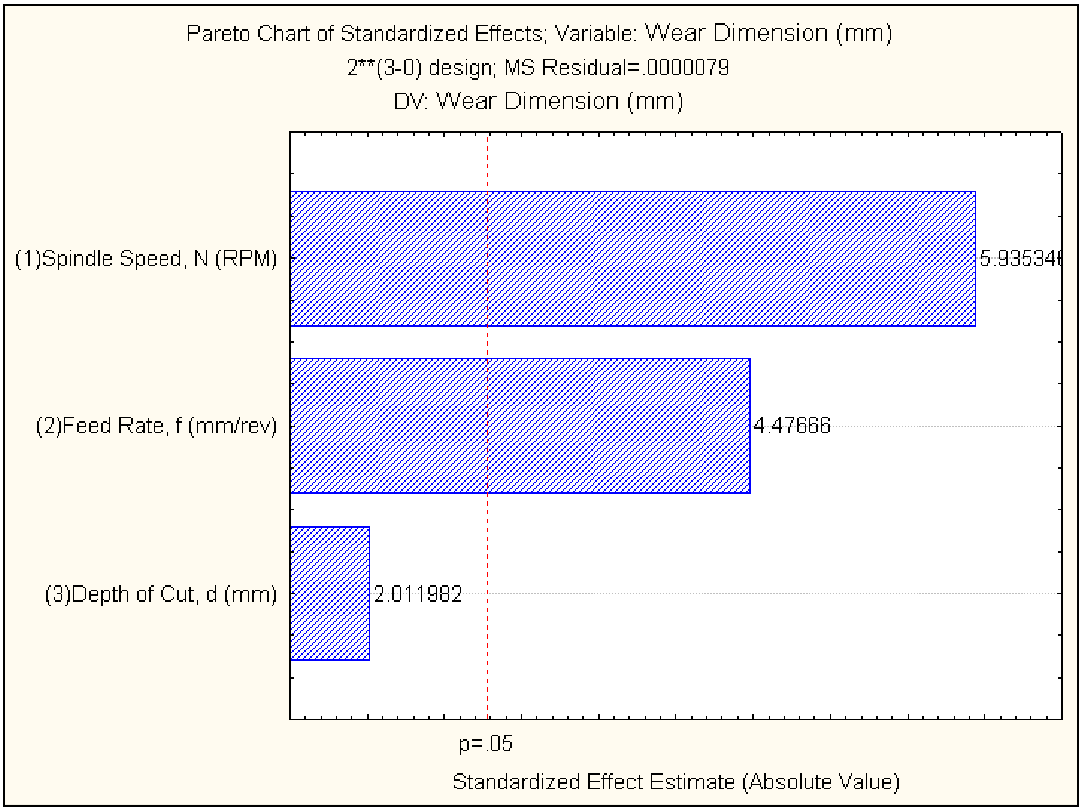


Figure 4.2: Pareto Chart of Standardized Effects; Variable: tool wear, mm.

From the Figure 4.2, view of the result of main effect is determined where the spindle speed, RPM contributes the maximum effect as main factor. That followed by the feed rate, mm where it still contributes large effect. Finally is depth of cut where the contribution of effect is small than the other parameters. This parameter can be independent variables because it does not give the significant effect to the tool wear.

The significant of main effects are determined where the p value $P<0.05$. The other factors and interaction factors which are not significant are $P>0.05$ and can discarded to produce a reduced model if desired. Their contribution to the variation then goes into error.

4.3.1 Tool Wear, mm

Again, all the results for tool wear have been analyzed. According to Figure 4.3 shows the higher spindle speed will be give the increase of tool wear. In addition, in Figure 4.4 and Figure 4.5 shows the tool wear is increased with the increasing in feed rate and depth of cut. The entire graph is a linear graph with tool wear is proportional to all factors but the slope is different where the larger slope means the larger effect is graph with a factor spindle speed followed by feed rate and depth of cut. For the Figure 4.5 shows the depth of cut does not give significant effect to tool wear because the graft is almost going to flat.

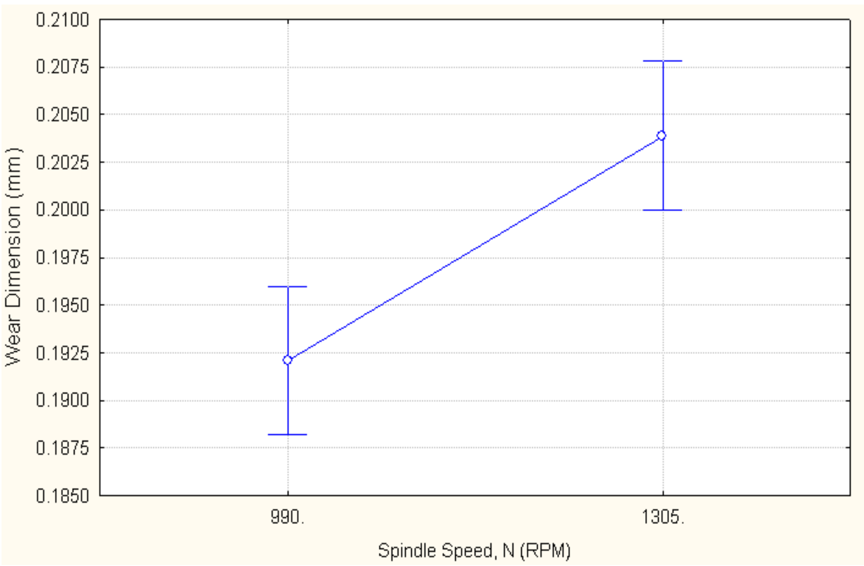


Figure 4.3: Graph of Wear Dimension (mm) versus Spindle Speed (RPM)

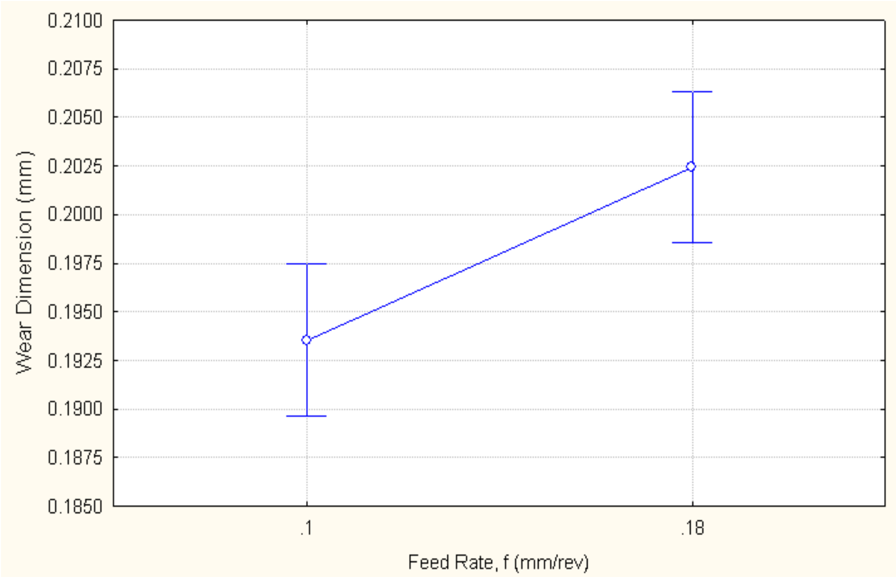


Figure 4.4: Graph of Wear Dimension (mm) versus Feed Rate (mm/rev)

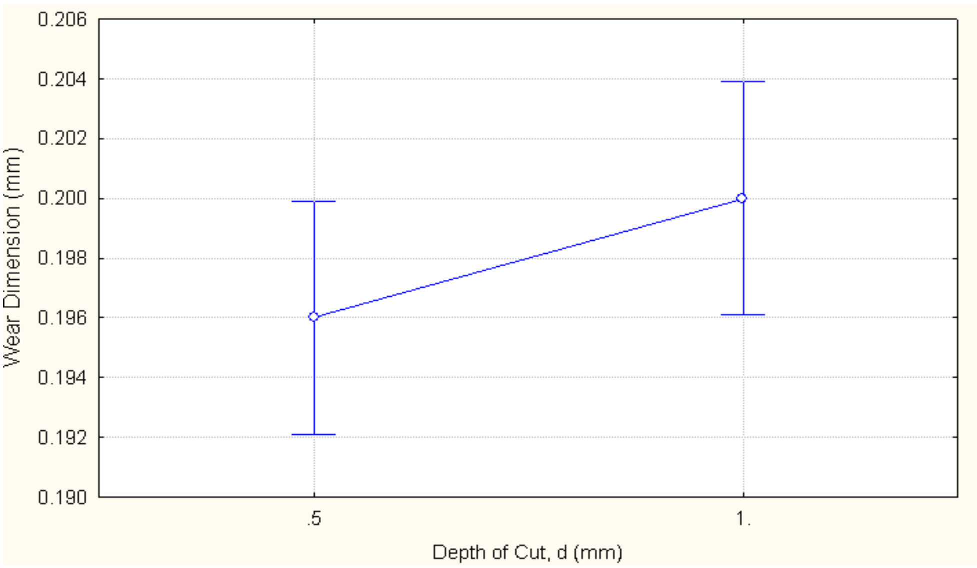


Figure 4.5: Graph of Wear Dimension (mm) versus Depth of Cut (mm)

4.4 Analysis of Variance (ANOVA)

Using the STATISTICA software, ANOVA applied to the results of experiment to determine the percentage contribution of each factors. This information showed of the factors need to be control and which are not.

According to the Table 4.3, there is degree of freedom that contributes error on result. The main factors that need to control or consider are spindle speed (RPM) and depth of cut (mm), which are highlighted with red font where these factors shows high statistical significant, SS and has value of $P<0.05$.

Table 4.3: The ANOVA effect of no interaction model

Factor	ANOVA; Var.:Wear Dimension (mm) 2**(3-0) design				
	SS	df	MS	F	p
(1)Spindle Speed, N (RPM)	0.000278	1	0.000278	35.22834	0.004040
(2)Feed Rate, f (mm/rev)	0.000158	1	0.000158	20.04048	0.011018
(3)Depth of Cut, d (mm)	0.000032	1	0.000032	4.04807	0.114540
Error	0.000032	4	0.000008		
Total SS	0.000501	7			

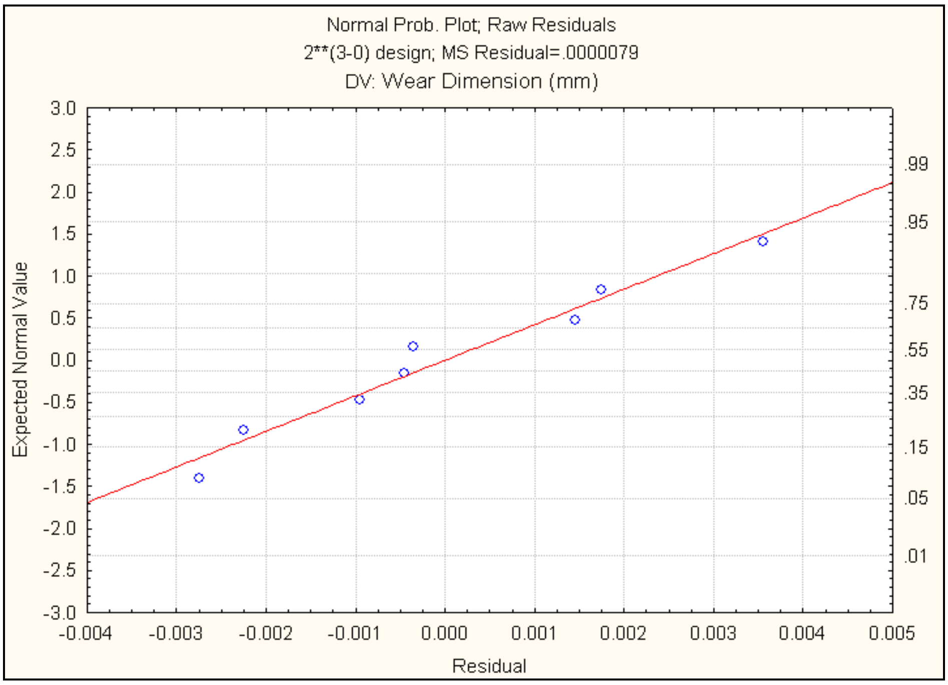


Figure 4.6: Normal Probability Residual plot to Expected Normal Value of effect

From Figure 4.6 shows the normality of the distribution of a variable, which is extent the distribution of the variable follows the normal distribution. The graph shows the results are proportional between residual and the expected normal values. All effect fall to response and this is an important outcome because all setting gives result to tool wear.

4.4.1 Interaction

Full Factorial Design of Experiment is the only method to discover interactions between variables. The knowledge of the interaction is more useful than knowledge of the main effect. A significant interaction can cover the significance of main effect. Other that, when interaction is present, the main effects of the factors can be determined either have interaction or not. In some experiment, the difference in response between the levels of one factor is not always same at all level to the other factors. When this occurs, there is an interaction between factors.

Figure 4.7, 4.8 and 4.9 demonstrate the interaction plot for wear dimension for each factor. There is no interaction between factors spindle speed and feed rate but however there are interactions between factors spindle speed and depth of cut and also factors feed rate and depth of cut.

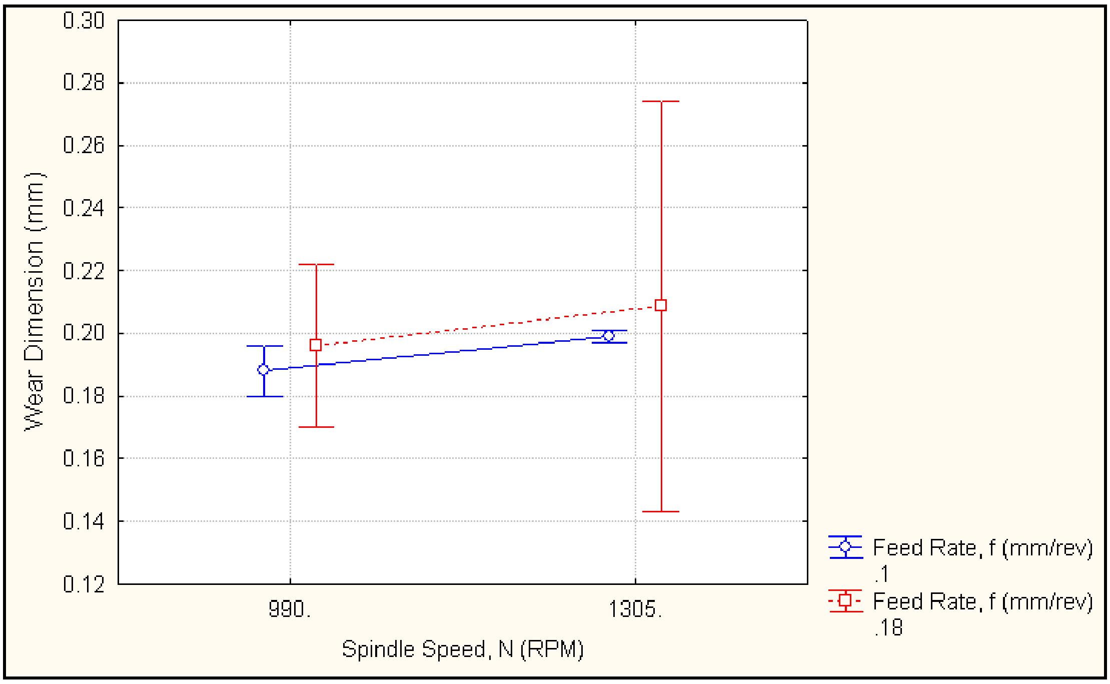


Figure 4.7: Graph of interaction plot for factors spindle speed and feed rate

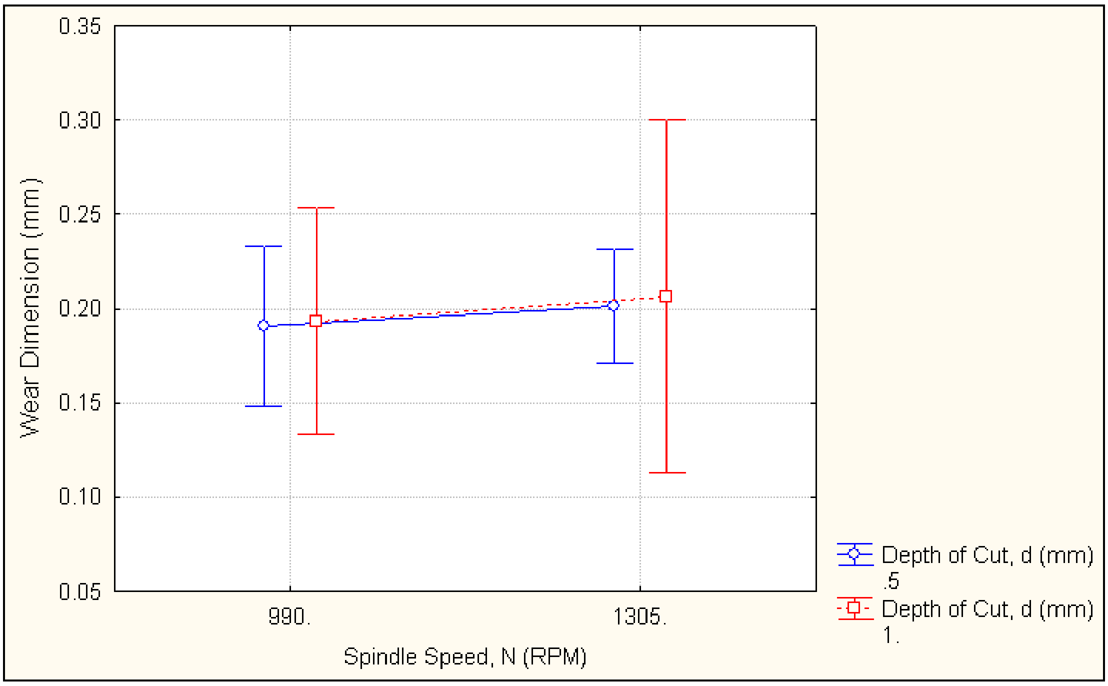


Figure 4.8: Graph of interaction plot for factors spindle speed and depth of cut

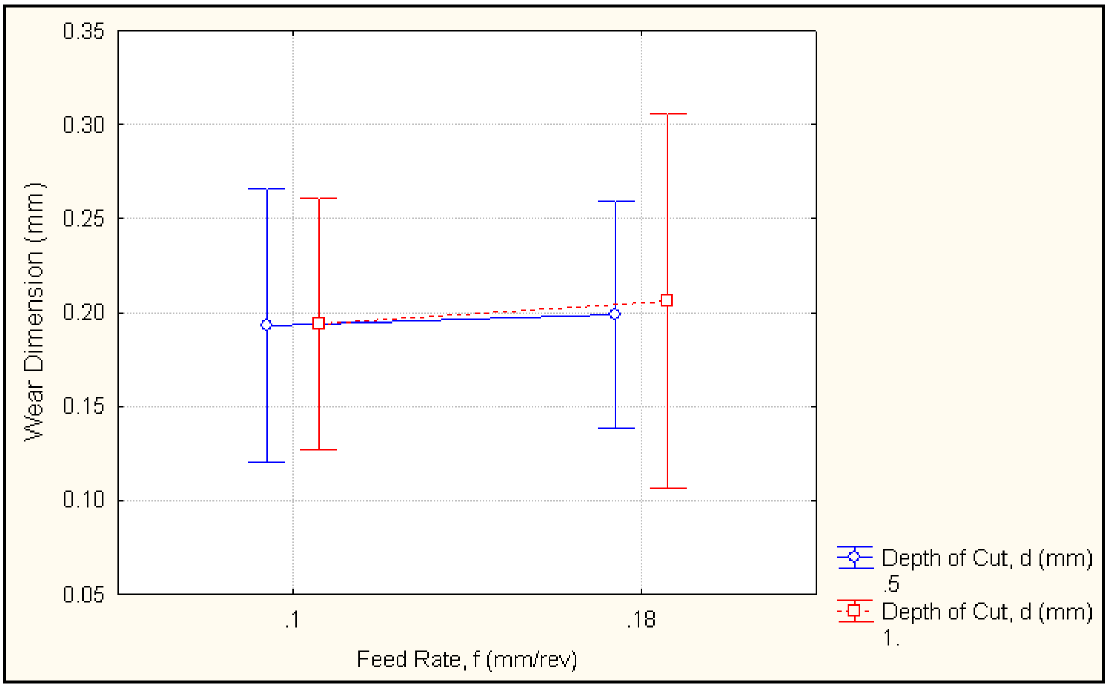


Figure 4.9: Graph of interaction plot for factors feed rate and depth of cut

4.5 Estimate Result at Optimum Condition

From Figure 4.10 present a three-dimensional surface plot of the data for depth of cut, d= 0.05 mm. Notice that the effect of the interaction between spindle speed (RPM) and feed rate (mm/rev) in the data is “twist” plane, so that there is curvature in the response function to the wear dimensions. If the data contain no interaction, the surface plot is a plane lying above the spindle speed and feed rate. Figure 4.11 shows the two –dimensional with the distribution effect of wear dimensions where the data is same. The higher value of spindle speed and feed rate contribute more wear effect and probably may cause of fatigue of the cutting tool.

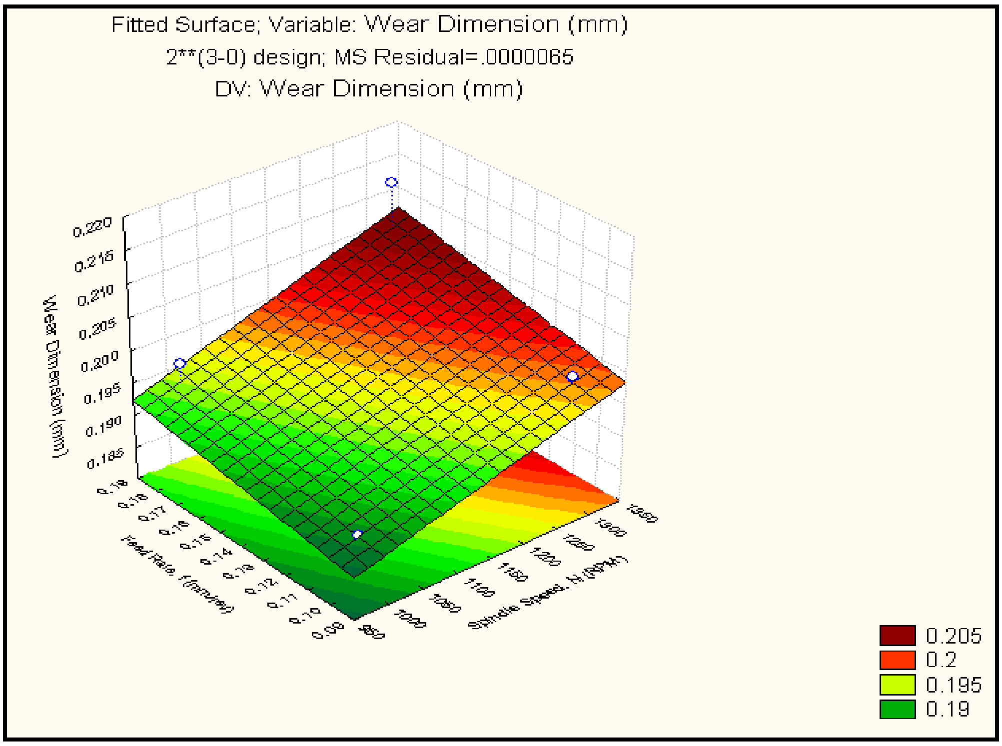


Figure 4.10: 3-D surface plots of the data main effects of the peak current and pulse on time.

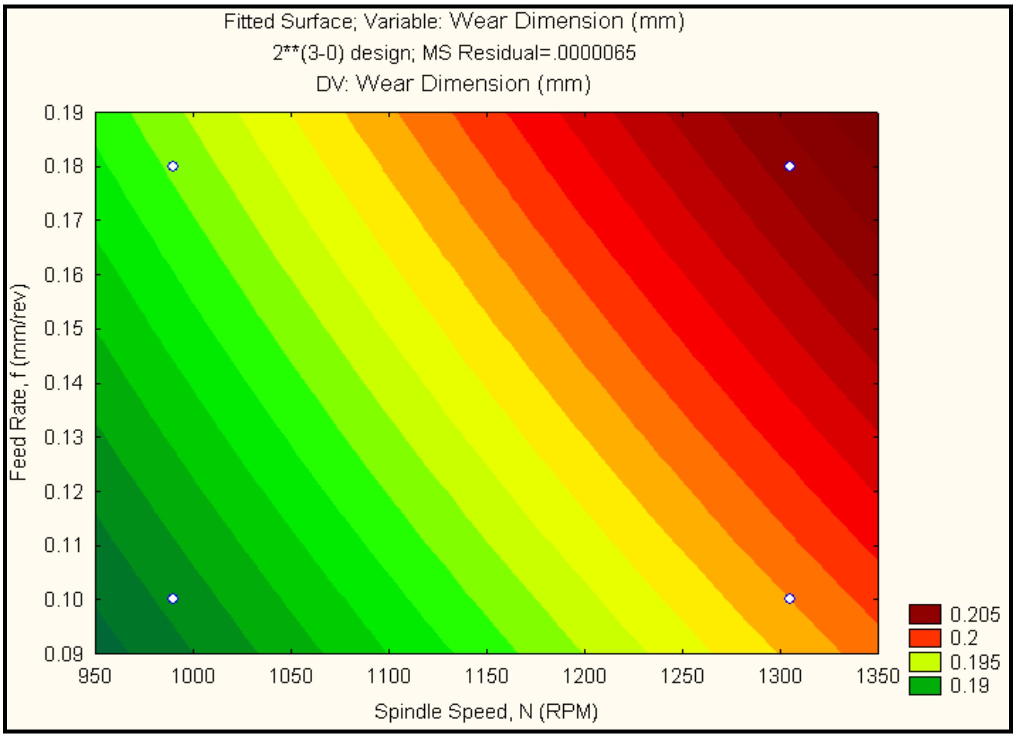


Figure 4.11: 2-D fitted surface distribution of effect between two factors

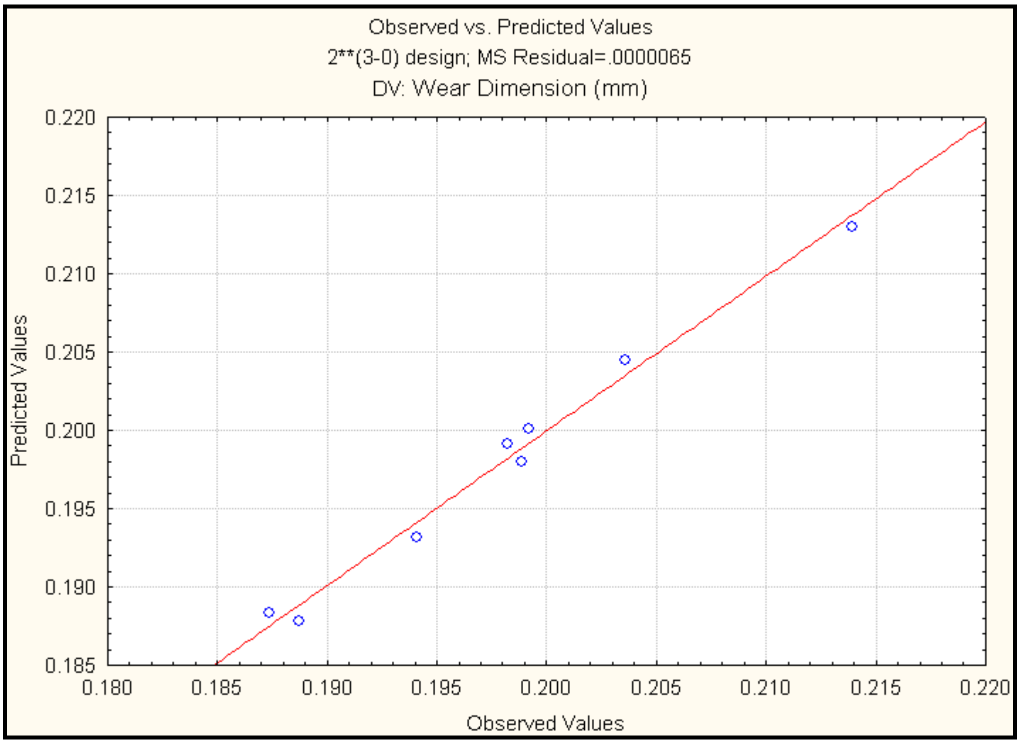


Figure 4.12: Observed Values versus Predicted Values plot

From Figure 4.12, observed-predicted values are linear and proportional. There is still having error because all the point on the linear line but the distribution is near the line. Overall result can be predicted based on the DOE methodology and STATISTICA software. The desired quality characteristics can be expressed in Table 4.4.

Table 4.4: Quality Characteristics of Machining Performance

Machining Characteristics	Quality Characteristics
Spindle Speed, N (RPM)	The smaller the better
Feed Rate, f (mm/rev)	The smaller the better

4.6 Confirmation Test

After significant parameters are obtained and the optimum result is identified, the confirmation tests need to be carried out. This is to ensure the theoretically predicted for optimum result will not to vary out of order. The followings are confirmation test result and the predicted value of surface roughness from STATISTICA based on optimum value as shown in Table 4.5 and Table 4.6.

Table 4.5: Confirmation test result

Spindle Speed (RPM	Feed Rate (mm/rev)	Depth of Cut (mm)	Wear Dimension (mm)
909	0.10	0.5	0.1884

Table 4.6: Predicted Value of Surface Roughness based on STATISTICA

Factor	Predicted Value; Var.:Wear Dimension (mm) 2**(3-0) design Regressn Coeff.	Value	Coeff. * Value
Constant	0.133439		
(1)Spindle Speed, N (RPM)	0.000037	909.0000	0.034051
(2)Feed Rate, f (mm/rev)	0.111250	0.1000	0.011125
(3)Depth of Cut, d (mm)	0.008000	0.5000	0.004000
Predicted			0.182616

4.7 Comparison Test

The comparison test between theoretically predicted and confirmation test results is a final consideration that will determine whether the optimum parameters predicted are in range. In this investigation, the range or sometimes called margin of error is set bellow than 10%. Margin of error is calculated as follows:

Error Margin (%) =
[{Predicted result- Confirmation test result}/ Conformation test result] * 100 (4.1)

Table 4.7 shows the comparison test between theoretically predicted and confirmation test result for differences set of data on the followings. From the table error margin is 3.08 % shows the result is below than 10 %, so that the result is in the range and can be accepted. This indicates that DOE Full Factorial method can be used in order to determine optimum parameters.

Table 4.7: Comparison test result

	Optimal Machining Parameter		Error Margin (%)
	Prediction (STATISTICA)	Experiment (confirmation test)	
Setting level	Spindle Speed= 909 RPM Feed Rate = 0.10 mm/rev Depth of Cut= 0.50 mm	Spindle Speed= 909 RPM Feed Rate = 0.10 mm/rev Depth of Cut= 0.50 mm	3.08
Wear dimension, mm	0.1826	0.1884	

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In order to optimize the cutting tool parameter to yield a lowest number of wear in process, a combination of knowledge in cutting tool properties, variable cutting tool parameters and workpiece material is very crucial. The use of Full Factorial Design of Experiment is very useful in analyzing the effect and interaction of the factors affecting the wear of the cutting tool.

5.1 CONCLUSION

From the result of the experiments, the result can be summarizing into several elements. There are few thing that effect the result of the experiments directly and indirect. The error may occur resulting of interference, unsuitable input or lack of real plan.

5.1.1 Effect of wear based on cutting tool parameters

The each of cutting tool parameters has their own effects such as flank wear and crater wear were cause by spindle speed. The factor that contributes largest effect of wear is spindle speed followed by spindle speed and depth of cut. Based on the result, the higher value of each factor may cause more damage on the cutting tool. To prevent the worst possible case may effect, the significant factor need to be control and using the value in range that suggested by experts or revision. Breakage may occur rather than wear if the parameter is too large or too low. The knowledge in cutting metal is crucial in order to maintain or extended the tool life.

5.1.2 Design of Experiment (DOE)

Predicting tool wear can be done if the noise can be neglected. Error in the result indicates the noise that affects the actual data. Relatively the result can be useful in order to determine the optimum factor, relationship, the percentage of factor contribution and tool life. DOE can be use in statistical analysis and widely more application in research or industrial analysis. The result obtain in STATISTICA are based on DOE methodology. So, the significant of the factor, interaction, ANOVA and etc are reliable and can be use in many situations. In the study, the result obtain can be as guidance or future references. DOE are applicable in research, learning or statistical analysis which cost and time effective. The number of the trials can be deducted and the accurate data can be achieved along with the error term.

5.2 RECOMMENDATIONS

In order to prevent tool wear during cutting process or extent the tool life, some recommendations could be implemented in future as below:

1) When study tool wear, the design should emphasize on the noise and any other factor that may effect on the wear dimension. The variety of wear should be considerate as the result. This action is to reduce the error and to investigate any other significant factor that leads to wear.

2) The use of different type of cutting tool material and workpiece material can assist for better understanding of its effect on tool wear.

3) Other improvement is possible by increasing the number of trials and evaluating more factors other than cutting tool parameter such as temperature, chip formation, cutting forces and cutting environment.

REFERENCES

[1] W.Y.H. Liew, B.K.A. Ngoi, Y.G. Lu, Wear characteristics of PCBN tools in the ultra-precision machining of stainless steel at low speeds, Wear 254 (2003) 265-267.

[2] D. Stovicek, Hard-part turning, Tooling and Production 57 (11) (1992) 25-26.

[3] G. Poulachon, B.P. Bandyopadhyay, I.S. Jawahir, Sebastien Pheulpin, The influence of the microstructure of hardened tool steel workpiece on the wear of PCBN cutting tools, International Journal of Machine Tools & Manufacture 43 (2003) 139-144.

[4] Serope Kalpakjian-Steven Schimd, Manufacturing Engineering and Technology, PEARSON, 2006, Fifth edition.

[5] Luo SY, Liao YS, Tsai YY. Wear characteristics in turning high hardness alloy steel by ceramic and CBN tools. J Mater Proces Technol 1999;88:114–21.

[6] Brandt G. Ceramic cutting tools, state of the art and development trends. Mater Technol 14:17–22.

[7] Cora Lahiff, Seamus Gordon, Pat Phelan, PCBN tool wear modes and mechanism in finish hard turning.

[8] Narutaki N, Yamane Y. Tool wear and cutting temperature of CBN tools in machining of hardened steels. Ann CIRP 1979; 28:23–8.

[9] Konig W, Komanduri R, Tonshoff HK, Ackershott G. Machining of hard materials. Ann CIRP 1984;33:417–27.

[10] W. Köing, A. Neises, Wear mechanisms of ultrahard, non-metallic cutting materials, Wear 162–164 (1993) 12–21.

[11] Farhat ZN. Wear mechanism of CBN cutting tool during high-speed machining of mold steel. Mater Sci Eng 2003;A361:100–10.

[12] S.A. Klimenko, Yu.A. Mukovoz, V.A. Lyashko, A.N. Vashchenko and V.V. Ogorodnik, On the wear mechanism of cubic boron nitride base cutting tools, *Wear* 157 (1992), pp. 1–7.

[13] Chou YK, Evans CJ, Barash MM. Experimental investigation on CBN turning of hardened AISI 52100 steel. J Mater Process Technol 2002;124:274–83.

[14] Barry J, Byrne G. Cutting tool wear in the machining of hardened steels Part II: cubic boron nitride cutting tool wear. Wear 2001; 247: 152-60.

[15] Steve F. Krar, Arthur R. Gill, Peter Smid, Technology of Machine Tools, Mc Graw-Hill International Edition, sixth edition pages 300-390.

[16] G. Poulachon, A. Moisan, I.S. Jawahir, Tool-wear mechanisms in hard turning with polycrystalline cubic boron nitride tools, Wear 250 (2001) 576-586.

[17] H.K. Tonshoff, C. Arendt, R. Ben Amor, Cutting of hardened steel, Keynote paper, Annals of the CIRP 49 (2) (2000) 547-566.

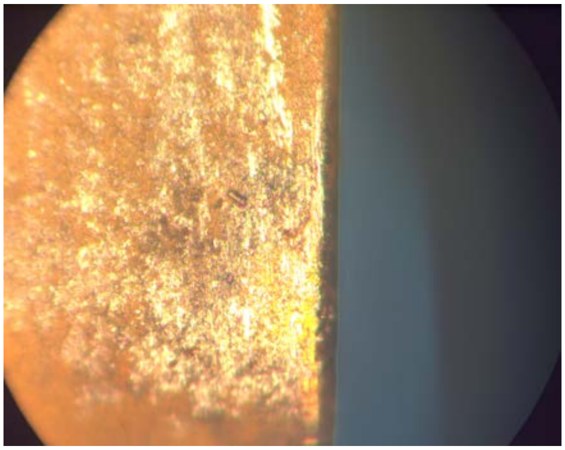
[18] Gustavo de Siqueira Galoppi, Marco Stipkovic Filho, Gilmar Ferreira Batalha, Hard turning of tempered DIN 100Cr6 steel with coated and no coated CBN inserts, Journal of Materials Processing Technology 179 (2006) 146–153.

[19] Mas Ayu H, Performance Evaluation of Wire Electrical Discharge Machining on Tungsten Carbide WC-Co, (Nov 2006) thesis, pg 30-33.

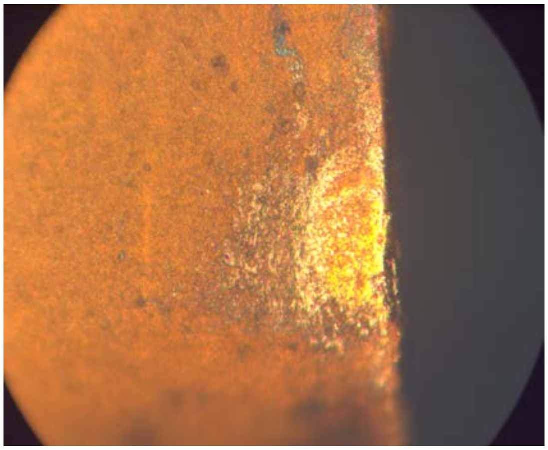
[20] Reginaldo T. Coelhoa, Eu-Gene Ngb, M.A. Elbestawib, Tool wear when turning hardened AISI 4340 with coated PCBN tools using finishing cutting conditions, International Journal of Machine Tools & Manufacture 47 (2007) 263–272

APPENDIX A

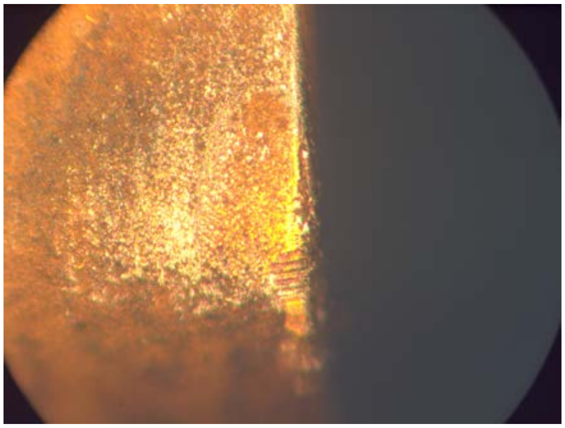
IMAGES OF FLANK WEAR



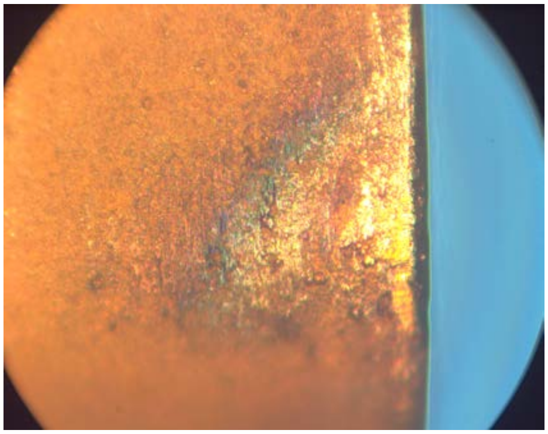
Experiment 1 (20x)



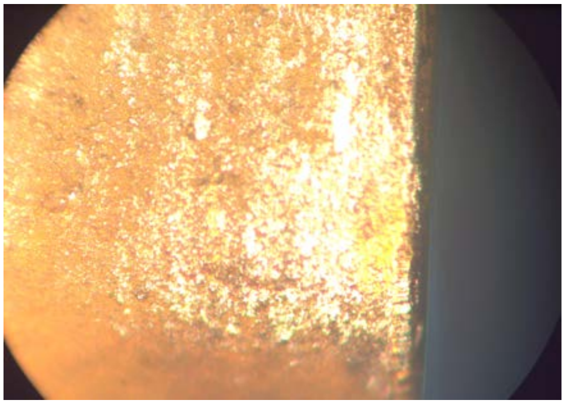
Experiment 2 (20x)



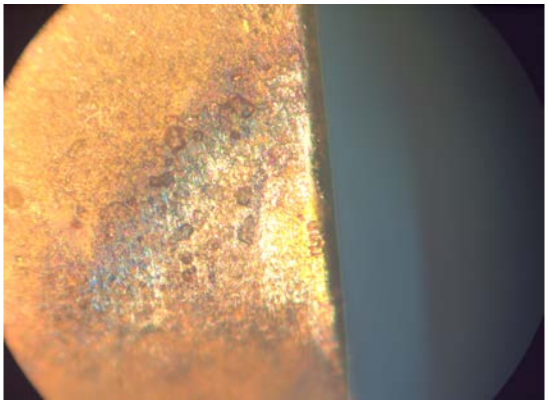
Experiment 3 (20x)



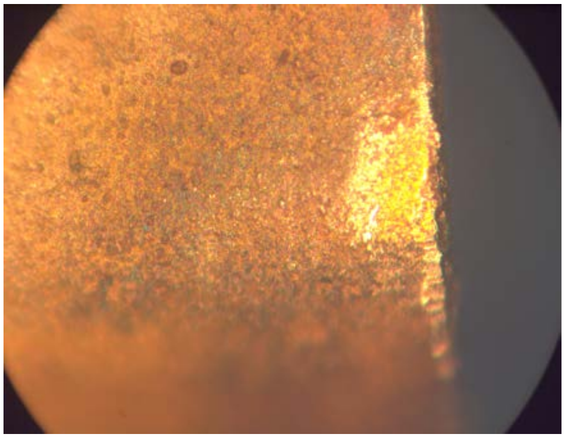
Experiment 4 (20x)



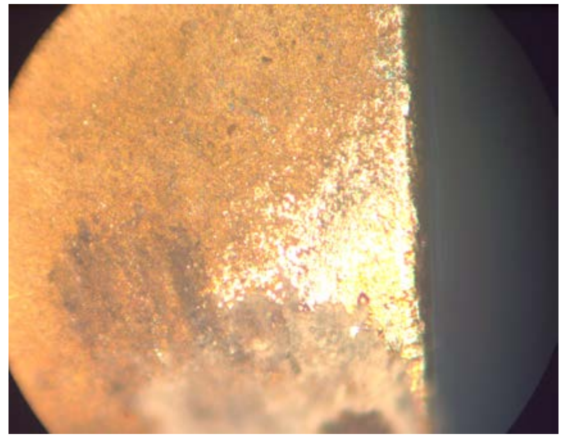
Experiment 5 (20x)



Experiment 6 (20x)



Experiment 7 (20x)



Experiment 8 (20x)

APPENDIX B

GANTT CHART

APPENDIX B-1: GANTT CHART OF FINAL YEAR PROJECT 1

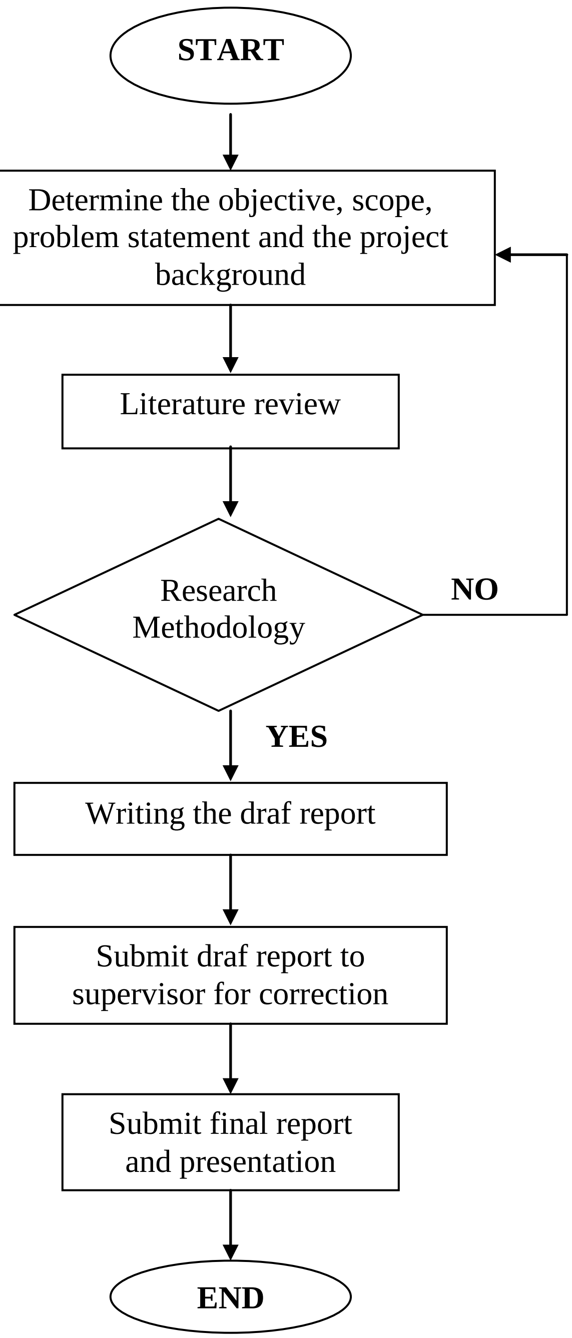
	Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1	Determine the objective, scope															
	and project background															
2	Literature Review															
	● Searching for Information about failure mechanism															
	● Get information about types and factors of tool wear															
3	Methodology of the project															
4	Write the draf report															
5	Submit draf report to supervisor for correction															
6	Submit final report and presentation															

APPENDIX B-2: GANTT CHART OF FINAL YEAR PROJECT 2

	Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1	Preparation of experiment tool and workpiece															
2	Experiment process (collect data, result analysis)															
3	Confirmation Test															
4	Write the draf report															
5	Presentation of FYP2															
6	Submit draf report to supervisor for correction															
7	Submit final report and presentation															

APPENDIX C

APPENDIX C-1: FLOW CHART OF FINAL YEAR PROJECT 1



APPENDIX C-2: FLOW CHART OF FINAL YEAR PROJECT 2