



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**Tool Wear Characterization of Carbide Cutting Tool
Insert in a Single Point Turning Operation of AISI D2
Steel**

Report submitted to Universiti Teknikal Malaysia Melaka in partial fulfillment
for Bachelor of Manufacturing Engineering
(Manufacturing Process)

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ABSTRACT

This study presents tool wear characterization of carbide cutting tool inserts in a single point turning operation of AISI D2 steel. An experiment was conducted in a 20 set of experiment matrix of cutting speed, depth of cut and feed rate and performed on a CNC lathe without coolant. Surface roughness was measured by Mitutoyo profilometer (SJ-301) and flank wear was measured by Axioskop 40. The data was compiled into Design Expert 7 software for analysis. From the result, depth of cut was found to be the main factor to have significant result on surface roughness followed by cutting speed and feed rate. No interaction between the factors was found to give significant effect to surface roughness. The most significant factor for the flank wear is the feed rate while the other two factors did not affected the flank wear. Interaction between depth of cut and feed rate was found to be the factors affected the flank wear. At the end of this study, optimization was made to produce minimum surface roughness and to produce minimum flank wear by suggesting the most suitable sets of parameter settings. Suggestion for both output response was also obtained from the optimization.

ABSTRAK

Kajian ini mendedahkan tentang sifat-sifat perkakas pemotongan sisipan karbaid melalui proses pemotongan satu titik putaran ke atas keluli AISI D2. Satu set eksperimen dengan 20 set nilai laju pemotongan, kedalaman potongan dan kadar potongan dijalankan menggunakan mesin larik CNC dalam keadaan kering tanpa menggunakan cecair pemotong. Kekasaran permukaan diukur menggunakan Mitutoyo profilometer (SJ-301) dan kehausan mata alat pemotongan diukur menggunakan Axioskop 40 dan data-data ini kemudian diisi ke dalam perisian Design Expert 7 untuk dianalisa. Daripada keputusan yang diperolehi, kedalaman pemotongan didapati menjadi faktor penting kepada penghasilan kekasaran permukaan diikuti oleh laju pemotongan dan juga kadar potongan. Tiada interaksi atau saling berpengaruh anantara factor didapati memberi kesan kepada kekasaran permukaan. Kadar potongan adalah faktor yang menjadi pengaruh kepada kehausan mata alat bukan dua lagi faktor yang terlibat. Interaksi antara kedalaman potongan dan kadar potongan juga menjadi faktor yang mempengaruhi kehausan mata alat.. Di akhir kajian, cadangan untuk setting parameter yang terbaik diberi bagi meminimumkan kekasaran permukaan dan juga meminimumkan kehausan mata alat. Cadangan bagi setting parameter terbaik untuk mendapatkan gabungan peminimuman kekasaran permukaan dan kehausan mata alat juga dibuat.

CHAPTER 1

INTRODUCTION

1.1 Background of project

Cutting tool commonly used in metalworking for roughing, drilling, semi finishing and finishing applications and they are also used in making metal objects and metal parts. There are many types of cutting tool that come in hundred of shapes, sizes and uses. Some of the most commonly used cutting tools are angle cutters, end mills, grinding wheels and turning tools.

Wear phenomena has become a nightmare in machining industry because it is absolutely affecting the quality of the product and also the tool life. There are two main types of wear in a cutting tool, flank wear and crater wear. Cutting tool plays an important role in producing good quality of products. Careful selection of cutting tool for machining process for its specific applications is imperative; to minimize the tool failure during machining process. So, the purpose of this study is to characterize the tool wear of carbide cutting tool insert in single point turning operation of AISI D2 steel.

According to Kalpakjian and Schmid (2001), cutting fluid account up to 15 percent of a shop's production costs. Cutting fluid especially that containing oil has become a huge liability. Because many high speed machining operations create air-borne mists, the amount of cutting fluid mists allow into the air has to be limited. Other than that, the cost of maintenance, record keeping and compliance with current and

proposed regulations is rapidly raising the price of cutting fluid hence many machine shops considering eliminating the costs by using dry cutting. Dry cutting is a machining process that uses no coolant during cutting process. Insert tools will perform better when the cutting temperature become higher because there is no coolant during cutting operation. Dry cutting process is able to cut the machining cost and it is also environmental friendly.

1.2 Problem statement

Tool wear will surely happen during machining process. Wear will affect the tool life and the products quality. Improvement needs to be done to increase the tool life. Tool wear characteristic and the effect have to be studied to improve both tool life and product quality. Basically, process parameter related with tool wear characteristic where different parameter will result in different degree of tool wear. From this, optimum parameter can be obtained that will produce minimum tool wear. This situation will produce better tool life performance thus producing good quality products efficiently.

1.3 Objectives

The main objectives of this research are:

1. To study influence of machining parameters such as cutting speed, feed rate and depth of cut to the tool wear of carbide insert.
2. To study the influence of machining parameters such as cutting speed, feed rate and depth of cut to the surface roughness of D2 steel.

3. To define the optimum machining parameter setting (cutting speed, feed rate and depth of cut) to minimize tool wear and surface roughness using RSM for single point turning carbide cutting tool insert on AISI D2 steel work material.

1.4 **Scope**

To ensure the objective is obtained, the study will be focused on:

1. Tool wear characterization of carbide cutting tool insert.
2. The tool wear to be analyzed are flank wear and crater wear.
3. The experiment will be done using dry cutting single point turning operation.
4. Machining parameters to be used are feed rate, cutting speed and depth of cut.
5. Work material which is AISI D2 steel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter covers the published work of researchers in the field of machining and cutting tools. In specific, it covers the study on the interaction between cutting parameters and resultant tool wear and surface roughness. Also included in this chapter are machining processes, cutting tool, tool wear, work material, surface roughness, influence of machining parameters to the tool wear and surface roughness followed by design of experiment.

2.2 Turning Process

Turning process is a basic operation that commonly used in metal cutting industry. The work material is held in the chuck of a lathe and rotated for producing products. The tool is held rigidly in a tool post and moved at a constant rate along the axis of the bar, cutting away a layer of metal to form a cylinder or a surface of more complex profile (Trent, 1977).

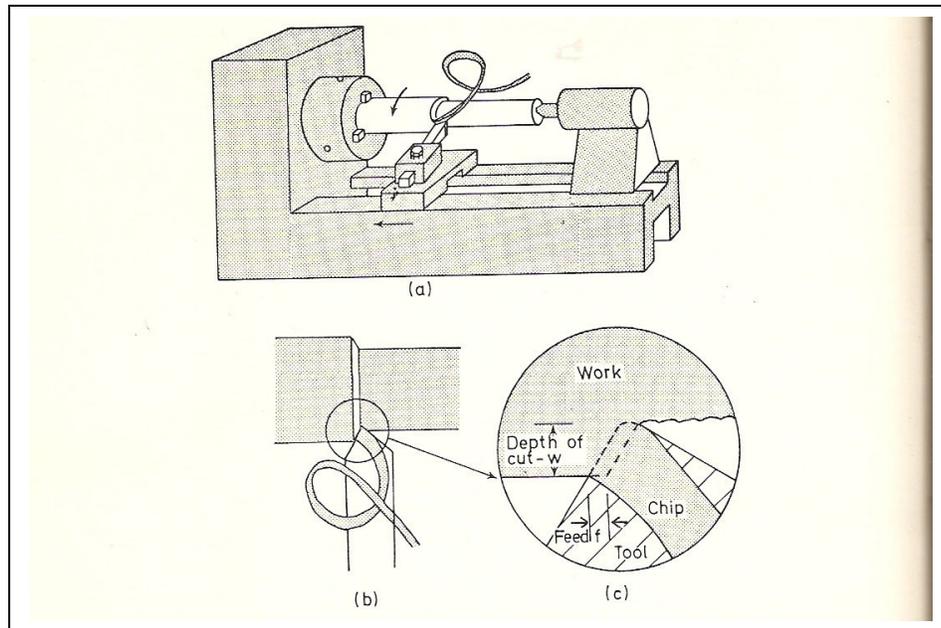


Figure 2.1 Turning process

Figure 2.1 (c) shows the feed rate (f), which is the distance moved by the tool in axial direction at each revolution of the work while Figure 2.1 (b) and (c) shows the depth of cut (w), which is the thickness of metal removed from the bar and measured in a radial direction. The cutting speed (V) means the rate at which the uncut surface of the work passes the cutting edge of the tool. The combination of these three gives the rate of metal removal. Basically, cutting speed and feed rate are adjusted to get optimum cutting conditions while depth of cut is fixed by the initial size of working material and products size.

2.2.1 Machining Parameters

Machining parameters are important factors that affect tool wear and surface roughness in any machining process. Recent studies stated that feed rate is the dominant factor on the surface roughness but it decreased with decreasing cutting speed, feed rate and depth of cut (Y. Sahin and A.R Motorcu, 2007) and another studies by Tugrul Ozel et al

(2007) shows that better tool life is obtained in lowest feed rate and lowest cutting speed combination. This study consists of three machining parameters which are cutting speed, feed rate, and depth of cut.

2.3 Cutting Tool

In general, cutting tool can be defined as part of a machine tool which removes material from the work piece by the used of a cutting medium. In industrial field, many types of cutting tool are used for machining process. Based on Schneider (2001), cutting tool need to have the certain characteristics:

1. **Hardness:** Hardness and strength of the cutting tool must be maintained at elevated temperatures also called hot hardness.
2. **Toughness:** Toughness of cutting tool is needed so that tools do not chip or fracture, especially during interrupted cutting operations.
3. **Wear Resistance:** Wear resistance means the attainment of acceptable tool life before tools need to be replaced.

Insert is one of the cutting tools that are widely used in machining process and it will be used as the cutting tool for this study. Brief explanation about insert will be featured in the next sub-topic.

2.3.1 Cutting Tool Insert

Inserts are individual cutting tool with several cutting points. Inserts are usually clamped on the tool shank with various locking mechanisms (Kalpakjian and Schmid, 2001). Most of high-performance cutting tools use the insert method. Inserts are normally made symmetrically so that when the first cutting edge is dull they can be rotated, presenting a

fresh cutting edge. This will effectively increase the life of the tool insert. Figure 2.2 shows some various shapes of insert.



Figure 2.2 Shapes of insert

2.3.2 Cutting Tool Insert Material

A wide range of cutting tool material is available with different properties and performance capabilities. These include carbides, carbon speed steels, cubic boron nitride, diamond and high speed steels. In this study, carbide is chosen as the cutting tool inserts material. Carbide was first developed in the 1930s, able to maintain their hardness over a wide range of temperatures, possesses high elastic modulus and thermal conductivity and low thermal expansion (Kalpakjian and Schmid, 2001). Carbides are among the most important, versatile and cost effective tool and die materials for a wide range of applications. The two basic groups of carbides used for machining operations are tungsten carbide and titanium carbide (TiC). In order to differentiate them from coated tools, plain carbide tools are usually referred to as uncoated carbides.

2.4 Tool Wear

Tool wear normally exist during machining process. In general, tool wear is a gradually process like the wear of the tip of an ordinary pencil. The rate of tool wear depends on tool and work piece materials, tool shape, process parameters and the machine tool itself (Kalpakjian and Schmid, 2001). Basically, tool wear will increase cutting force and cutting temperature and also produce poor surface finish. There are various types of tool wear such as flank wear, crater wear, and build up edge, glazing and edge wear. This study will be focusing on flank wear and crater wear.

2.4.1 Flank Wear

Flank wear occurs on the flank of a cutting tool and caused by friction between the newly machined work piece surface and the contact area on the tool flank. Because of the rigidity of the work piece, the flank wear land must be parallel to the resultant cutting direction and normally the width of the wear land will be taken as the measurement of the amount of wear. This situation is shown in Figure 2.3.

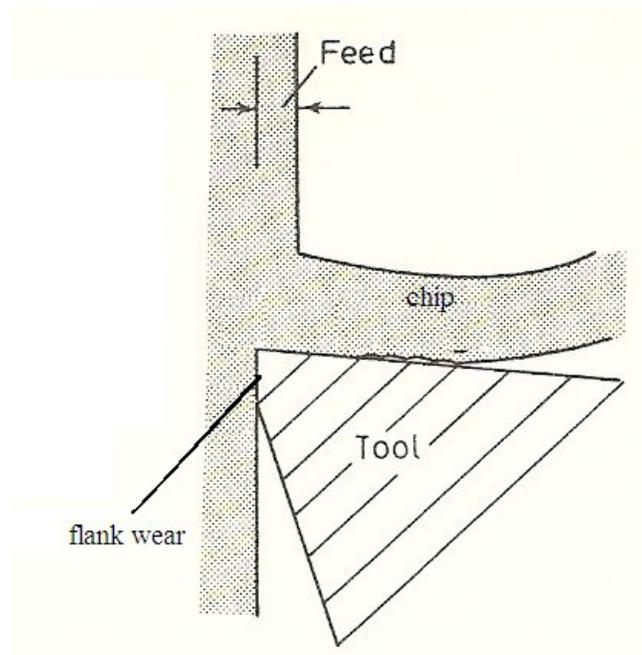


Figure 2.3 Flank Wear

2.4.2 Crater Wear

Based on Kalpakjian and Schmid (2001), cratering typically occurs on top face of the tool and it is essentially the erosion of an area parallel to the cutting edge. This erosion process takes place as the chip being cut and rubs the top face of the tool. Under very high speed cutting conditions and when machining tough materials, crater wear will become the factor that determines the life of the tool. Crater wear location is shown in Figure 2.4.

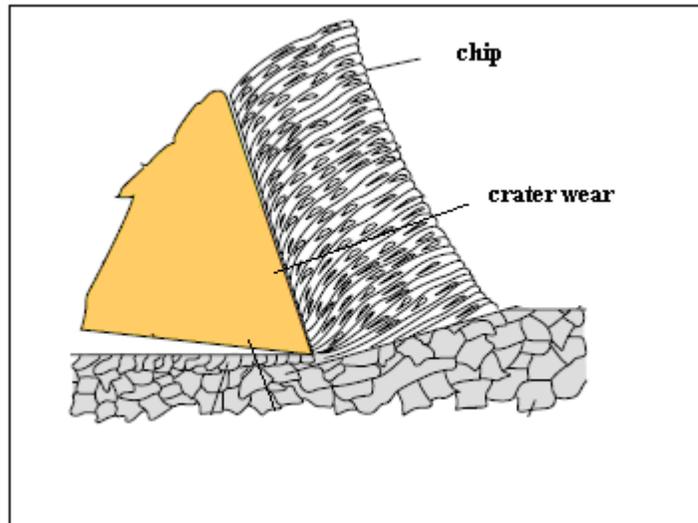


Figure 2.4 Crater wear

2.4.3 Tool Wear Measurement

There are certain criteria that need to be considered when measuring tool wear and there are different type of instruments that can be used to measure tool wear. Tool wear geometry is the most important criteria in measuring the wear and all those criteria are shown in Figure 2.5.

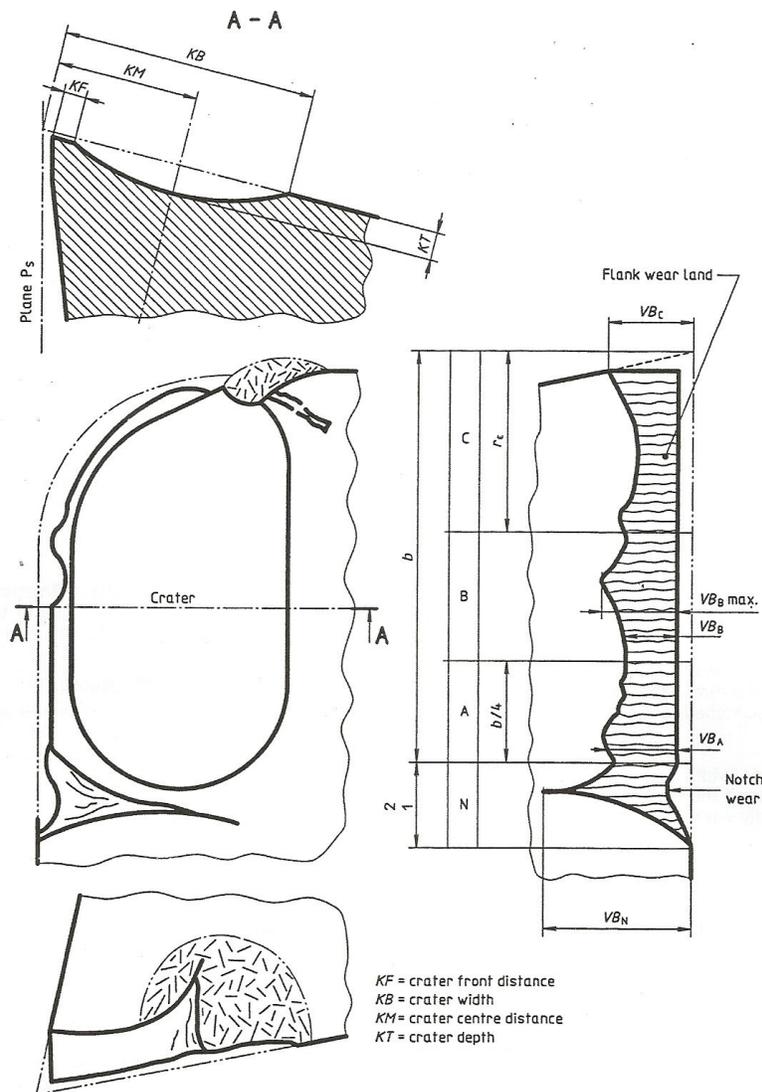


Figure 2.5 Wear on turning tools. Source: ISO 3685:1993(E)

The major cutting edges are divided into four zones:

1. Zone C is the curved part of the cutting edge of the tool corner.
2. Zone B is the remaining straight part of the cutting edge between zone C and zone A.
3. Zone A is the quarter of the worn cutting edge length b farthest away from the tool corner.

4. Zone N extends beyond the area of mutual contact between the tool and work piece for approximately 1mm to 2mm along the major cutting edge and the wear is notch type.

The width of the flank wear land VB_B shall be measured within zone B in the tool cutting edge plane P_s perpendicular to the major cutting edge. The width of the flank wear land shall be measured from the position of the original major cutting edge. The crater depth KT shall be measured as the maximum distance between the crater bottom and the original face in zone B.

2.5 Work piece Material

AISI D2 is a high carbon, high chromium tool steel alloyed with molybdenum and vanadium. J.A. Arsecularatne et al (2006) pointed out that AISI D2 steel is a high chromium, high carbon, tool and die steel with hardness used for cold working operations. It has a high strength, very high resistance to cracking and high resistance to softening and wear while its toughness and machinability are considered to be low. According to American Iron and Steel Institute (AISI), AISI D2 steel is characterized by:

1. High wear resistance.
2. High compressive strength.
3. Good through hardening properties.
4. High stability in hardening.
5. Good resistance to tempering back.

This material is used in this study because it is widely used harden steel in industrial field; hence it can generate the tool wear with minimal machining time.

2.5.1 Properties

The compositions of D2 steel are shown in Table 2.1 below:

Table 2.1: AISI D2 steel composition

Element	Weight %
C	1.40-1.60
Mn	0.60
Si	0.60
Cr	11.00-13.00
Ni	0.30
Mo	0.70-1.20
V	1.10
Co	1.00
Cu	0.25
P	0.03
S	0.03

2.5.2 Applications

D2 steel is used for tools requiring very high wear resistance combined with moderate toughness (shock resistance) and it can also be supplied in various finishes, including the hot rolled, pre mechanical and fine machined condition. Some of the applications of D2 steel are listed down below:

1. Coining Dies
2. Cold Extrusion Dies
3. Thread Rolling Dies
4. Crushing Hammers
5. Knurling Tools

2.6 Surface Roughness

Surface roughness is an important element in a product and its quality depends on same factors as the tool wear which is machining parameters. According to J.A. Arsecularatne et al (2006), the surface roughness increases with the increase in tool wear. Surface roughness is a measurement of the small scale variations in the height of a physical surface. It is generally described using two methods; arithmetic mean and root-mean-square average. The arithmetic mean value, Ra, formerly identified as AA for arithmetic average or CLA for center line average. The arithmetic mean value, Ra, is defined as

$$Ra = \frac{a + b + c + d + \dots}{n} \quad 2.6a$$

where all ordinates a, b, c,.... are absolute values and n is the number of readings. The root mean square average, Rq, is identified as RMS and defined as

$$Rq = \sqrt{a^2 + b^2 + c^2 + d^2 + \dots} \quad 2.6b$$

The datum line AB in Figure 2.6c is located so that the sum of the areas above the line is equal to the sum of the areas below the line. The units generally used for surface roughness are μm (micrometer or micron) or μin (microinch).

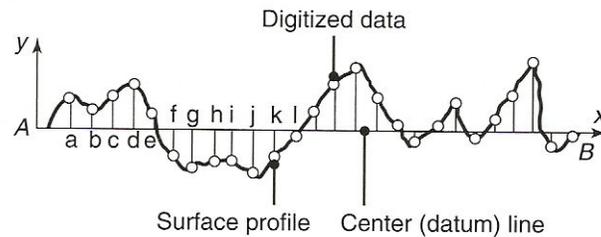


Figure 2.6(c) Coordinates used for surface roughness using equation 2.6 (a and b)

Because of its simplicity, the arithmetic mean value (R_a) was adopted internationally in the mid 1950s and is used widely in engineering practice (Kalpakjian and Schmid). Both equation show that there is a relationship between R_a and R_q and this is shown by the ratio R_a/R_q . Generally, a surface cannot be described by its R_a or R_q value one because these values are averages. Two surfaces may have the same roughness value but have actual topography which is very different.

2.6.1 Symbols for Surface Roughness

According to Kalpakjian and Schmid, acceptable limits for surface roughness are specified on technical drawings by symbols. Symbols used to describe a surface specify only its roughness, waviness and lay and they do not include flaws. Therefore, a special note is included in technical drawings to describe the method which should be used to inspect for surface flaws. Figure 2.7 shows the standard symbols for engineering surfaces.

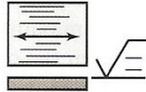
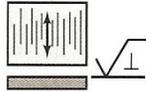
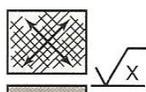
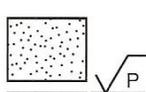
Lay symbol	Interpretation	Examples
—	Lay parallel to the line representing the surface to which the symbol is applied	
⊥	Lay perpendicular to the line representing the surface to which the symbol is applied	
X	Lay angular in both directions to line representing the surface to which the symbol is applied	
P	Pitted, protuberant, porous, or particulate nondirectional lay	

Figure 2.7 Standard lay symbols for engineering surfaces

2.6.2 Measuring Surface Roughness

Commercially available instruments called surface profilometers are used to measure and record surface roughness. The most commonly used instruments feature a diamond stylus which travels along a straight line over the surface. The distance that the stylus travels called cutoff and generally ranges from 0.08mm to 25mm or 0.8mm. The range is typical used for most applications. The rule of thumb is that the cutoff must be large enough to include 10 to 15 roughness irregularities as well as surface waviness. In order to highlight the roughness, profilometer traces are recorded on an exaggerated vertical scale and the magnitude of the scale is called gain on the recording instrument. The recorded profile is significantly distorted and the surface appears to be much rougher than it actually is. The recording instrument reads surface waviness thus presenting only roughness. Because of the finite radius of the diamond stylus tip, the path of the stylus is less rough than the actual surface. The most commonly used tip diameter is 10 μ m

(400 μ in). The smaller the diameter and the smoother the surface, the closer the path of the stylus to the actual surface profile. Surface roughness can be directly observed through an optical or scanning electron microscope.

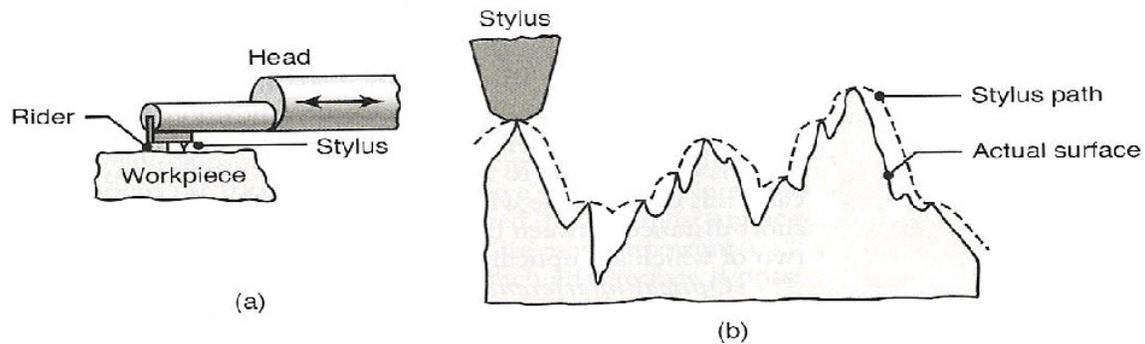


Figure 2.8 (a) Measuring surface roughness with a stylus. (b) Path of stylus in surface roughness measurements compared to actual roughness profile.

2.7 Machining Parameters, Tool Wear and Surface Roughness Interaction

Surface roughness is very important due to manufacturing needs particularly in producing products and its quality depends on many factors such as work material, cutting tool and cutting condition. There are lots of experiments that have been done to investigate the quality of surface roughness using different machining parameters.

Some of these studies showed that surface roughness was influenced by feed rate and cutting speed. The results of the study using response surface methodology (RSM) on a turning process showed that feed rate was found to be dominant factor on the surface roughness but it decreased with decreasing cutting speed, feed rate and depth of cut (Sahin and Motorcu, 2007). Palanikumar and Khartikeyen (2007) stated that the factor that has greater influence on surface roughness is feed rate followed by cutting speed.

As for the tool wear, the wear phenomenon also occurs due to machining parameters and many studies have been completed in order to look into this problem. Regarding to studies on surface finish and tool flank wear in turning of AISI D2 steel with ceramic wiper inserts, tool flank wear reaches to a tool life criterion value at high cutting speed. The studies also stated that better tool life is obtained in lowest feed rate and lowest cutting speed combination (Ozel et al, 2007). Another study on cutting tool wear assessment by Astakhov (2004) conclude that the properties of the work and tool material, tool geometry and the cutting regime determine the contact phenomena of the tool-work piece interface. As such, the cutting speed has the strongest influence. Studies about tool wear in turning have been made in order to develop reliable method to predict flank wear precisely using a mathematical model. The mathematical model formulated estimate the flank wear by means of the diffusion coefficient and the other input cutting parameters. The wear is shown experimentally that the cutting velocity and the index of diffusion have the most significant effect followed by the feed and the depth of cut (Choudhury and Srinivas, 2004).

2.8 Design of Experiment (DOE)

Design of experiment (DOE) is a structured method that is used to determine the relationship between the different input factors and the output response of that process. When the result of these experiments is analyzed, it helps to identify optimal condition and the factors that most influence the results (NIST, 2006).

This DOE method is used for the study because it gather knowledge based on the analysis of experimental data and provide analysis that can explain relationship between input parameters and output response. This enable optimization of the process to be made. DOE is widely used in research and development because it optimizes the resources to complete the experiment. Some of the methods that can be used as design of

experiments are Factorial experiments, Taguchi methods and Response Surface Methods.

2.8.1 Response Surface Methodology (RSM)

Response surface methodology (RSM) is a statistical mathematical method which uses quantitative data in an experimental design to determine and solve multivariable equation in order to optimize processes or products. This method is used to obtain optimum results with minimum run of experiment. An important aspect of RSM is the Central Composite Design (CCD) where CCD is very useful for building a second order or quadratic model for the response variable without needing to use a complete three-level factorial experiment (NIST, 2006).

The method is used using Design Expert Software. Expected matrix is developed using the software based on the input parameters and range specified. According to NIST (2006), the advantages of RSM are:

1. Simplified equation representing a complex system
2. Sensitivities are easily obtained
3. Optimization is easily obtained
4. Rapid and efficient
5. The use of RSM allows for bringing more knowledge earlier in the design process
6. Enabling technique for Advanced Design approaches
7. Instantaneous evaluations

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the methods for completing this project. The explanation covers tool work and material, cutting condition, the experiment details and data collection followed by data analysis and report. Figure 3.1 shows the methodology flow chart of this project.

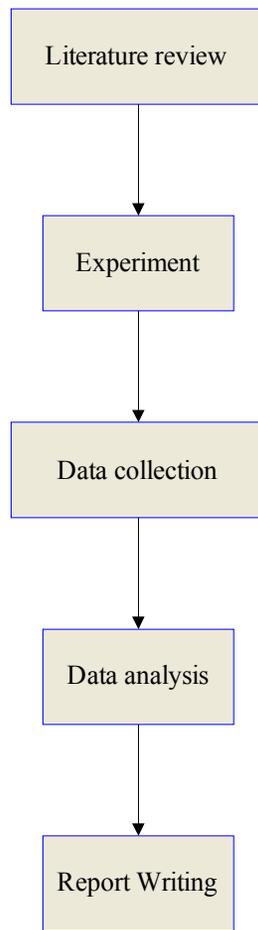


Figure 3.1 Methodology flow chart

3.2 Literature Review

Literature review was done by gaining as much information regarding the study. All the information was collected from references books, journals, internet, and recent studies of researchers in the field of machining and cutting tools. Machining test was carried out in turning AISI D2 steel using carbide cutting tool insert. Machining parameters evaluated in this study are cutting speed, feed rate and depth of cut. Information for both tool wear and surface roughness and how to measure them are also explained in this chapter.

3.3 Experiment

3.3.1 Tool and Work Material

The experiment was conducted according to ISO 3685 (1993) test for single-point turning operation and the cutting insert used are carbide insert (ISO SPGN 120308). The tool holder used (FP11R-44A) was manufactured by Sumitomo Hardmetal and the work material used for this study is AISI D2 X 155 CrVMo 12 1. Table 3.1 and 3.2 below shows the material specifications and work material composition.

Table 3.1: Material specifications

Material	Specification
Carbide ISO SPGN 120308 Manufacturer: Sumitomo Electric Hardmetal	Square type $l = 12.7$ ($\text{Ø}d=12.7$) $S = 3.18$
Work material: KRUPP 2379 X 155 CrVMo 12 1	AISI D2 steel, $d = 100$ mm Length = 250 mm

Table 3.2: Work material composition

Element	Composition (%)
C	1.55
Cr	12
V	1
Mo	0.7

3.3.2 Cutting Condition

This experiment is carried out using CNC lathe HAAS (SL-20T). The machining parameters for this study were chosen according to previous study by M. Mohd Razali et al (2006) and the ranges are: cutting speed (v_s) of 200-500 m/min, feed rate (f) of 0.3-0.5 mm/rev and depth of cut (a) of 0.2-0.5 mm.

The turning process was studied with a standard RSM design called a central composite design (CCD) where the factorial portion is a full factorial design with all combinations of the factors at two levels. The main points are at the face of the cube on the design which related to an α -value of 1. This is referred as face centered CCD and the center points. The response variables investigated are the surface roughness and the flank wear.

3.3.3 Experimental Design

The experimental design was based on Central Composite Design and three inputs for the experiment (cutting speed, feed rate and depth of cut) are keyed in to get the experiment matrix using Design Expert 7 software package. The experiment consists of 8 factorial points, 6 axial points and 6 center points. The experiment matrix that has been obtained from Design Expert 7 is shown in Table 3.3.

Table 3.3: Experiment matrix

Std	Run	Block	Factor 1	Factor 2	Factor 3	Response 1	Response 2
			A:Cutting	B:Depth of	C:Feed	Flank wear	Surface roughness
			speed	cut	rate		
			m/min	mm	mm/min		
11	1	Block 1	350.00	0.10	0.40		
12	2	Block 1	350.00	0.60	0.40		
10	3	Block 1	602.27	0.35	0.40		
2	4	Block 1	500.00	0.20	0.30		
9	5	Block 1	97.73	0.35	0.40		
13	6	Block 1	350.00	0.35	0.23		
3	7	Block 1	200.00	0.50	0.30		
15	8	Block 1	350.00	0.35	0.40		
16	9	Block 1	350.00	0.35	0.40		
14	10	Block 1	350.00	0.35	0.57		
8	11	Block 1	500.00	0.50	0.50		
7	12	Block 1	200.00	0.50	0.50		
1	13	Block 1	200.00	0.20	0.30		
20	14	Block 1	350.00	0.35	0.40		
17	15	Block 1	350.00	0.35	0.40		
4	16	Block 1	500.00	0.50	0.30		
18	17	Block 1	350.00	0.35	0.40		
19	18	Block 1	350.00	0.35	0.40		
5	19	Block 1	200.00	0.20	0.50		
6	20	Block 1	500.00	0.20	0.50		

The experiment will have 20 runs as indicated in Table 3.3. Two output responses which are flank wear and surface roughness will be collected from this experiment.

3.4 Data Collection

Data collected from the experiment are classified as the output responses of the experiment which are the tool wear and surface roughness. Both outputs were measured to get the interaction between the input parameters. The tool wear is measured using