VOT 78055

FEASIBILITY STUDY OF USING VEGETABLE OIL AS A CUTTING LUBRICANT THROUGH THE USE OF MINIMUM QUANTITY LUBRICATION DURING MACHINING

(KAJIAN KEBOLEHAN PENGGUNAAN MINYAK SAYUR SEBAGAI PELINCIR PEMOTONG MELALUI KAEDAH KUNTITI PELINCIR MINIMUM SEMASA PEMESINAN)

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RESEARCH VOT NO:
78055

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2009

FEASIBILITY STUDY OF USING VEGETABLE OIL AS A CUTTING LUBRICANT THROUGH THE USE OF MINIMUM QUANTITY LUBRICATION DURING MACHINING

(Keywords : vegetable oil, machining, minimum quantity lubrication, surface quality, tool life)

In machining, the occurrence of tool wear is a natural phenomenon which may lead to tool failure. The deformation during cutting at the interface between the tool face and workpiece tends to generate high cutting temperature. This condition reduces the tool life and the surface quality of the workpiece. The application of flood coolant to reduce the friction at the tool-workpiece may create several environmental problems. The introduction of Minimum Quantity Lubrication (MQL) as an alternative technique which is the process of pulverizing a very small amount of oil (< 30ml/h) can be regarded as replacement of dry machining while it may also be considered as an alternative to flood cooling. The research focused on the feasibility of using palm oil as cutting lubricant through the use of MQL during end milling hardened STAVAX ESR stainless steel of hardness 50 HRC with TiAlN and AlTiN coated carbide tools. The effect of various kind of lubricant and cutting speed on tool life, tool wear, cutting forces and surface integrity. The application of this 'green machining' would improve the plant environment, reduce the pollution, minimize the industrial hazard, reduce the machining cost and prolonged the tool life.

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KAJIAN KEBOLEHAN PENGGUNAAN MINYAK SAYUR SEBAGAI PELINCIR PEMOTONG MELALUI KAEDAH KUNTITI PELINCIR MINIMUM SEMASA PEMESINAN

(Kata kunci : minyak sayuran, pemesinan, kuantiti pelincir minimum, integriti permukaan, hayat mata alat)

Didalam proses pemesinan, kehausan mata alat adalah sebuah fenomena semula jadi yang akan mengakibatkan kegagalan mata alat pemotong. Pembentukan bahan semasa pemotongan di antara muka mata alat dan bendakerja akan meningktkan kenaikan suhu pemotongan yang tinggi. Keadaan ini akan menurunkan jangka hayat mata alat dan kualiti permukaan bendakerja yang dimesin. Penggunaan cecair penyejuk yang banyak dan berterusan bagi mengurangkan geseran antara mata alat dan bendakerja akan menimbulkan beberapa masalah pada alam sekitar. Pengenalan aplikasi kuantiti pelincir minimum (*MQL*) sebagai teknik alternatif yang menggunakan jumlah minyak pelincir yang sangat sedikit (30ml/h) boleh dijadikan pengganti bagi pemesinan kering dan juga sebagai alternatif untuk cecair penyejuk yang banyak. Dalam penyelidikan ini penggunaan minyak sawit sebagai pelincir pemotongan dengan menggunakan *MQL* telah dinilai semasa proses mengisar STAVAX ESR keluli tahan karat dengan kekerasan 50 HRC. Mata alat karbida yang bersalut TiAlN dan AlTiN telah digunakan dalam kajian ini. Kesan dari penggunaan pelincir minyak sawit dan halaju pemotongan terhadap hayat mata alat, kehausan mata alat, daya pemotongan dan integriti permukaan telah dikaji. Penggunaan terhadap *'green machining'* akan mempertingkatkan kualiti alam sekitar, mengurangkan pencemaran, mengurangkan bahaya industri dari industri dan kos pemesinan dan yang lebih penting adalah peningkatan hayat mata alat.

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DEDICATION

In the name of Allah, the most Gracious and most Compassionate

We would like to thank Allah the Almighty for His blessing and giving us the strength to accomplish this project. A special thank to the Ministry of Higher Education (MOHE), Malaysia for providing the Fundamental Research Grant Scheme (FRGS) for this project, the Research Management Centre, Universiti Teknologi Malaysia (RMC UTM) in managing the research fund, the Faculty of Mechanical Engineering especially the Production Laboratory for allowing the use of the various equipments for this research. Many thanks to all of the researchers and the technicians involved and for their cooperation and assistance towards the success of the project.

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LIST OF SYMBOLS

V	-	cutting speed (m/min)
π	-	phi (3.14)
D	-	cutter diameter (mm)
N	-	spindle speed (rpm)
f_t	-	feed per tooth
Vf	-	feed rate (mm/tooth)
N	-	number of tooth
l	-	length of workpiece (mm)
w	-	width of cut or radial depth of cut (mm)
d	-	depth of cut or axial depth of cut (mm)
t	-	cutting time
MRR	-	Material/metal removal rate
MQL	-	Minimum Quantity Lubrication
NDM	-	Near Dry Machining
SEM	-	Scanning electron microscopy
SR	-	Surface Roughness

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CHAPTER 1

INTRODUCTION

1.1 Background

Machining process is an important part in manufacturing of metal components such as mold and die. It was indicated that the costs in producing die are 20% are attributed to raw material, 10% to the assembly, 5% to the heat treatment and 65% to the machining processes. Tool steels such to AISI group D are used widely used in die and mould industries an account of their excellent wear resistance and deep hardening characteristics. The increase of manufacturing productivity is related on reduce of manufacturing cost. Therefore the aimed for reduce manufacturing cost especially on machining is interested topic for research today. The study will describe the results of application of different coolant strategies includes dry milling, flood coolant application and minimum quantity lubricant (MQL) to end milling of tool steel.

Coolant is very essential in machining because it can reduce the cutting temperature and ease the removal of chips and metal debris from the tool and work piece interface. Despite the wide recognition of the aforementioned, when inappropriately handled, cutting fluids may create several environmental problems such damaging the soil and polluting the water resources. In addition, the skin or health of the operators may be affected by the chemical effects of the cutting fluids (Sokovic and Mijanovic, 2001). In addition, the costs related to cutting fluids are higher than those related to cutting tools (Klocke and Eiseblatter, 1997). Today, modern manufacturing operations employ MQL which can be regarded as replacement of dry machining while it may also be considered as alternative to flood cooling. MQL or mist coolant is a new machining method that delivers the required minimum quantity of lubrication mixed with air and performs machining through a continuous of this oil/air mixture to the tool tip (Rahman et. al, 2002). This method is also called semi dry machining and near dry machining. MQL is the process of pulverizing a very small amount of oil or lubricant (<30 ml/h) in a flow of compressed air (Braga et. al, 2002). By minimizing the quantity of cutting fluids during machining, not only the thermal expansion is suppressed, the machining forces can also be reduced more than by the supply of the same amount of oil droplets alone (Itogawa et. al, 2005).

Several studies on the application of MQL in machining of steel had been conducted Rahman et. al (2002), Braga et. al (2002), Itogawa et. al (2005), Khan and Dhar, (2006), Heinemann et. al (2006), Liao and Lin (2007) and Attanasio et. al (2005). Rahman et al (2005) conducted an experiment on milling ASSAB 718 H steel with uncoated carbide inserts using MQL and flood coolant with flow rate of 8.5 ml/h and 42000 ml/min. Unlike fracture in flood cooling or flaking in dry cutting, the inserts used with MQL were still in serviceable condition despite the presence of higher width of flank wear. The results exhibited that the MQL may be considered as an economical and environment compatible lubrication technique for low speed, feed rate and depth of cut. Experiments conducted by Khan and Dhar (2006), indicates that using vegetable oil as cutting lubricant through the MQL technique provides the benefits mainly by reducing the cutting temperature, improving the surface finish, dimensional accuracy and cutting forces

1.2 Problem Statement

Cutting fluids have long been used in machining processes to decrease the temperature during machining by spraying the coolant into the machining zone directly on the cutting tool and the part. This has the effect of decreasing the tool temperature, which increases tool life and improves the part quality. However, cutting fluids are environmentally unfriendly, costly, and potentially toxic (Weinert et. al, 2004). The recent shift to dry cutting has not completely solved the problem. Dry cutting increases energy costs, increases per part costs, and requires a capital investment that is too large for most machine shops.

The new alternative to traditional use of cutting fluids is Minimum Quantity Lubricant (MQL), also known as Near Dry Machining (NDM) or semi-dry machining. MQL uses a very small quantity of lubricant delivered precisely to the cutting surface. Many advantages are realized through the use of MQL and the reduction of cutting oil consumption. These include improvement of the plant environment; improvements in chip recycling, reduction of electricity consumption, increased tool life, a "greener" environment, and a decrease of machine maintenance due to contamination by coolant. In addition, the using of vegetable oil as alternative bio-lubricant such as palm oil can be carried out.

Different workpiece material with different property and microstructure gives different effect to the cutting tool performance. No general equation can be used to closely estimate the tool life for a given tool grade, cutting condition and workpiece material. In this research, coated and uncoated carbides tools will be used to evaluate the tools performance when machining 50 HRC hardened stainless steel workpiece.

Most published research involved machining through the use of minimum quantity lubricant (MQL) by using vegetable oil as cutting lubricant have been concerned mainly with the turning, drilling and grinding process. There are no researches published nowadays for end milling of STAVAX ESR through the use of minimum quantity lubricant (MQL) by using palm oil-based as cutting lubricant.

CHAPTER 2

LITERATURE STUDY

Hardened steels are widely used in automotives, bearing and tool and die industry. Machining of hardened steel may replace some of the grinding process. Machining hardened steel increase productivity and products with complex geometrical shape can be realized since the machining set-up is easier compared to grinding. The micro hardness of hardened steel is the main factor in abrasive wear of tool.

W.Y.H. Liewa and X. Ding (2007) mentioned that when end milling hardened stainless steel, the tool was predominantly subjected to abrasive wear throughout the duration of testing followed by cracking and chipping. Furthermore, it was found that the cutting fluid was effective in preventing catastrophic failure of the tool. M.Y. Noordin et. al. (2007) when conduct dry hard turning by using coated cermet and coated carbide tools, indicated that the flank and end clearance wear probably occur by both abrasive and adhesive wear mechanisms with abrasive wear being the major source of material removal since the temperatures at the tool flank are lower than that on the rake face. Catastrophic failure could be associated with a combination of abrasion, adhesion, diffusion, fracture and plastic deformation wear mechanisms.

Many researchers have done experiment to machine hardened stainless steel such as S.Y. Luo et. al. (1999), J. Barry and G. Byrne (2001), A. Senthil Kumar et. al (2003) and Hongming Geng et. al. (2008) under various types of machining process by using different type of tools. Found of a variety of the result in term of tool life, surface integrity and wear mechanism when they conducted to machine hardened stainless steel.

The hardened STAVAX ESR stainless steel (AISI 420 modified) was classified into martensitic stainless steel. This material was chosen in this research since it was currently use for all types of mould.

2.1 Milling Operation

Milling is the process of cutting away material by feeding a workpiece past a rotating multiple tooth cutter. The cutting action of the many teeth around the milling cutter provides a fast method of machining. The machined surface may be flat, angular, or curved. The surface may also be milled to any combination of shapes. The machine for holding the workpiece, rotating the cutter, and feeding it is known as the Milling machine.

2.1.1 End Milling

An end mill is one of the indispensable tools in the milling processing. The end mill has edges in the side surface and the bottom surface. The fundamental usage is that the end mill is rotated, and makes a plane of a material in the right-and-left direction or a plane of a bottom side of the end mill. Flat surface as well as various profile can be produced by end milling.

Milling processes can be further divided into up (or conventional) milling and down (or climb) milling operations. If the axis of the cutter does not intersect the workpiece, the motion of cutter due to rotation opposes the feed motion in up (or conventional) milling but is in the same direction as the feed motion in down milling. When the axis of the cutter intersects the workpiece, both up and down milling occur at different stage of rotation. Both up and down milling have advantages in particular application. Up milling is usually preferable to down milling when the spindle and feed drive exhibit backlash and when the part has large variations in height or a hardened outer layer due to sand casting or flame cutting. In down milling, there is a tendency for the chip to become wedged between the insert or cutter, causing tool breakage. However, if the spindle and drive are rigid, cutting forces in peripheral down milling tend to hold the part on the machine and reduce cutting vibrations.

The rotating speed as known as the cutting speed, V, in milling is the peripheral speed of the cutter, or

$$V = \frac{\pi \times D \times N}{1000}$$

where D is cutter diameter (mm) and N is the rotational spindle speed (rpm) of the cutter. The unwanted material is removed through the formation of chips when the tool is fed. Feed per tooth is determined from the equation:

$$f_t = \frac{v_f}{N \times n}$$

Where v_f is the linear speed (feed rate) of the workpiece and n is the number of teeth on the cutter peripheral. The depth of cut is limited by the amount of material that needs to be removed from the workpiece, by the power available at the machine spindle, and by the rigidity of the workpiece, tool and setup. Besides that, the volume of material removed per unit time, such as mm^3/min or in^3/min can be determined. In milling process; it can be expressed as follows:

$$MRR = \frac{l \times w \times d}{t} = w \times d \times v_f$$

where l is the length of workpiece (mm), w is the width of cut or radial depth of cut (mm), d is the depth of cut or axial depth of cut (mm) and t is the cutting time (min).

Looking on end milling performance, many factors that need to be considered for successful machining. It can be seen in Figure 2.1, that several factors influenced the machining performance when end milling of any material.

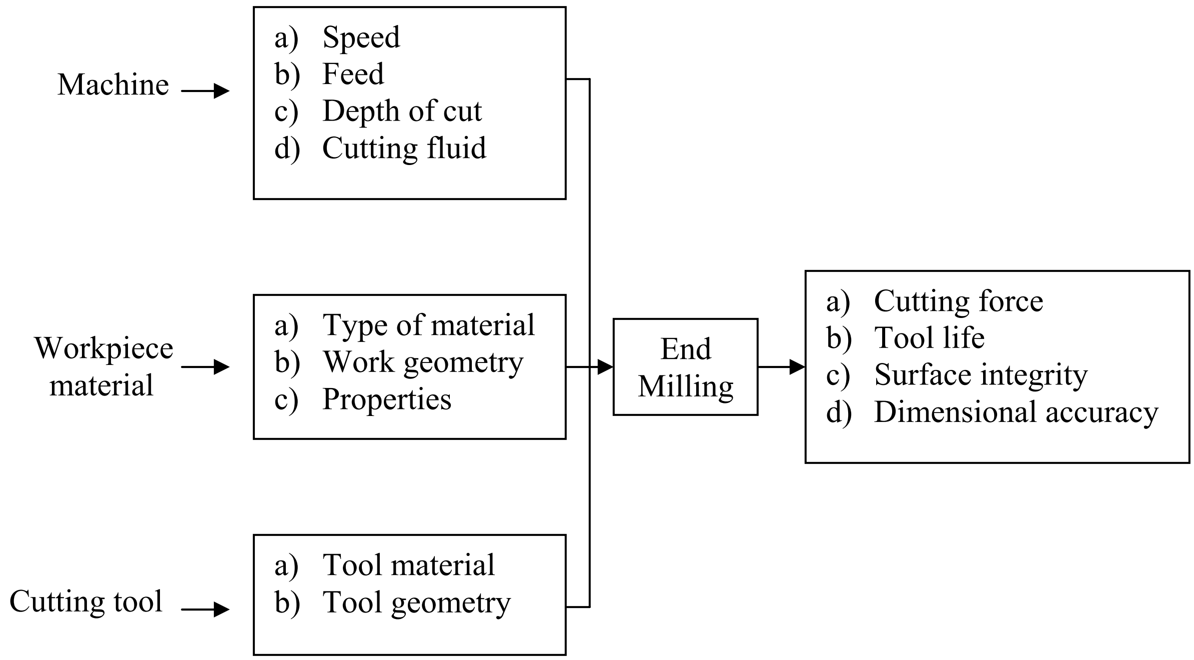


Figure 2.1: Factor influencing the end milling of material

2.2 Tool and Tool Material

The development of tool material and coating improved machinability of hard material. The cutting tool is subjected to high temperature, contact stresses and sliding along the tool-chip interface and along the machined surface. The cutting tool must possess the hardness, toughness, wear resistance and chemical stability characteristic. Various cutting tool materials with a wide range of mechanical, physical and chemical properties are available. There are High Speed Steel (HSS), Cemented Carbide Tools, Ceramic and Cermet Tool, and Superhard Materials.

. In order to reduce tool wear in metal cutting, more than 80% of commercial cutting tools and inserts used in the industry are coated with various coatings. When the properly coated carbide with the right edge preparation is used in the right application, it will generally outperform any uncoated grade. Coating reduces friction; lower cutting temperatures, increase wear resistance and thus increase tool life. The two most common processes are chemical vapor deposition (CVD) and physical vapor deposition (PVD). The most popular CVD coatings are titanium nitride (TiN), titanium carbide (TiC), aluminium oxide (Al_2O_3) and diamond (D). Similarly, most popular PVD coatings are titanium nitride (TiN), titanium carbon nitride (TiCN), titanium aluminium nitride (TiAlN) and diamond (D).

2.3 Cutting Fluid

Metal cutting processes are one of the most important manufacturing operations. Due to high temperature and adhesion between the chip and tool in cutting operation, cutting fluid are used as well as to countermeasure these problem. On the others hand, they also promote cool workpiece to avoid thermal expansion besides more easily to handling. When a lubricant is taking a part as a cutting fluid, it provides a rust-proof layer to the finished work surface which does not have protective surface layers.

The main function of cutting fluid are includes cooling and lubricating. Coolant is an agent in cooling to cool the cutting tool and workpiece. Cooling is useful when the heat generate from the cutting process is high. The developed of high heat is due to increase of cutting speed and depth of cut. A secondary function of metalworking fluid is to remove chips and metal fines from the tool/work piece interface. To prevent a finished surface from becoming marred, cutting chips generated during machining operations must be continually flushed away from the cutting zone. Application of cutting fluid also reduces the occurrence of built-up edge (BUE). BUE formation causes increased friction and alters the geometry of the machine tool. This, in turn, affects work piece quality, often resulting in a poor surface finish and inconsistencies in work piece size.

Cutting fluids have long been used in machining processes to decease the temperature during machining by spraying the coolant into the machining zone directly on the cutting tool and the part. This has the effect of decreasing the tool temperature, which increases tool life and improves the part quality. However, A change in environmental awareness and increasing cost pressures on industrial enterprises have led to a critical consideration of conventional cooling lubricants used in most machining processes. Depending on the workpiece, the production structure, and the production location the costs related to the use of cooling lubricants range from 7 - 17% of the total costs of the manufactured work piece. Besides an improvement in the efficiency of the production process, such a technology change makes a contribution to the protection of labor, Chen, Z (1999) and the environment, Rossmoore, H. W., 1995.

2.3.1 Alternative to Cutting Fluids

In the pursuit of environmental, profit, safety, and convenience, a number of alternatives to traditional machining are currently under development. Dry machining has been around for as long as traditional machining, but has seen a recent surge in interest as more people are realizing the true cost of cutting fluid management. There are some alternatives to replace cutting fluids such as dry machining, minimum quantity lubricant and liquid nitrogen technology. Toward the ‘greener machining’, several benefits of dry as shown in Figure 2.2.

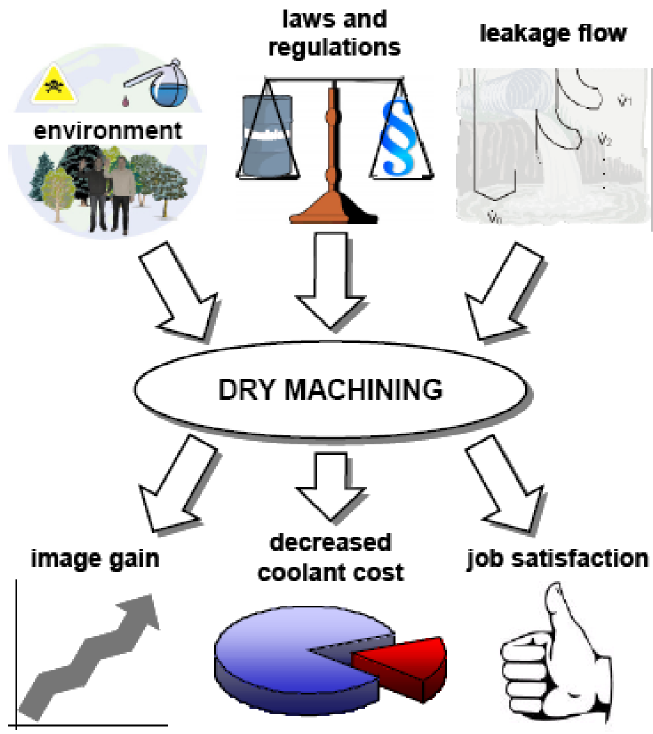


Figure 2.2 : Benefits of dry machining

However, the implementation of dry machining cannot be accomplished by simply turning off the cooling lubricant supply. In fact, the cooling lubricant performs several important functions, which, in its absence, must be taken over by other components in the machining process. Many researchers reported that in term tool performance, dry machining is not right way compared to flood coolant. Thus, the introduction of minimum quantity lubrication is another alternative to dry and flood coolant machining.

2.4 Minimum Quantity Lubricant Technique

Minimum Quantity Lubricant (MQL), also known as Near Dry Machining (NDM) or semi-dry machining, is alternative to traditional use of cutting fluids. There are many similarities between dry machining and MQL, in fact, many research papers treat true dry machining and MQL as the same technology. As the name implies, MQL uses a very small quantity of lubricant delivered precisely to the cutting surface. Often the quantity used is so small that no lubricant is recovered from the piece. Any remaining lubricant may form a film that protects the piece from oxidation or the lubricant may vaporize completely due to the heat of the machining process. With the large volumes of cutting fluid used in traditional machining, misting, skin exposure, and fluid contamination are problems that must be addressed to assure minimal impact on worker health. With MQL, the problem of misting and skin exposure is greatly reduced, and fluid does not become contaminated because it is not re-used. However, fluid is still present. Proper ventilation is required to prevent buildup of vaporized fluid.

The method of mixing-inside-spindle is better method to supply MQL to tool tip as shown as Figure 2.3. By using mixing inside spindle method, the lubricant and the carrier gas are separately supplied inside spindle, and MQL was created near the cutting tool. In this method, all supplied lubricant can be discharged. On the other hand, in mixing outside spindle, MQL is created at the upper stream from the spindle of machine tool and supplied to tool tip via piping and spindle. In this case, the only deliverable smoke type lubricant can be supplied. Both are the methods to supply MQL inside spindle through center, however, the mixing inside spindle method has superior features in response, stability, and control of quantity of MQL discharge. The performance required for MQL in machining center is to discharge the required quantity of MQL through tool without affected by spindle rotation without delay. Also, it is necessary to preset easily the MQL quantity for each tools.

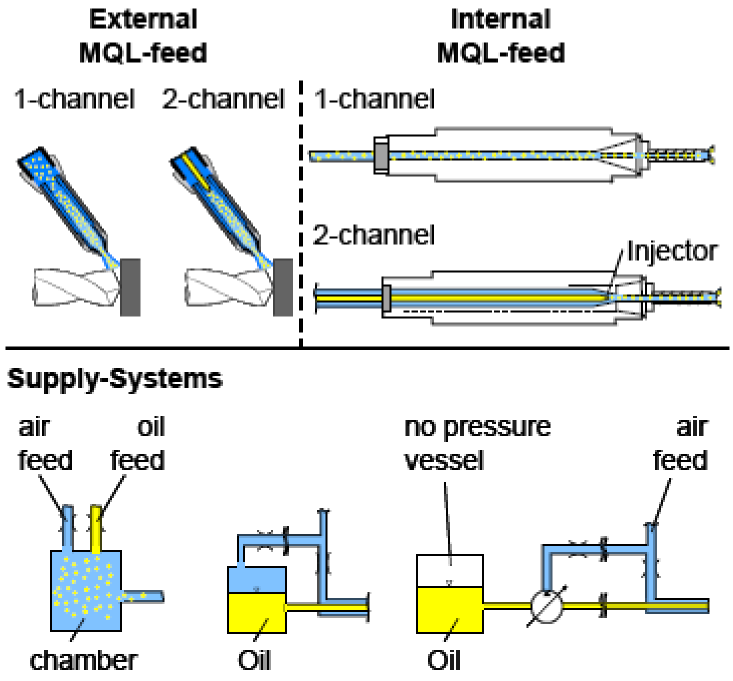


Figure 2.3: MQL-Feed system

2.4.1 MQL - Media

In near-dry machining operations with MQL supply, however, secondary characteristics as biodegradability, oxidation stability and storage stability, are even more important because the lubricants must be compatible with the environment and chemically stable under long-term usage when there is a very low consumption rate, Suda, S (2002). With this in mind, some description of lubricant performance regarding secondary characteristics is important.

Because of biodegradability characteristic, Fatty alcohols and synthetic esters (chemically modified vegetable oil) are the media most commonly used in MQL. Other characteristics of synthetic ester and fatty alcohol shown in Table 2.1.

Table 2.1: Characteristics of synthetic esters and fatty alcohol

Synthetic esters	Fatty alcohols
Chemically modified vegetable oils	Long-chained alcohols made from natural raw materials or from mineral oils
- good biodegradeability - low level of hazard to water - toxicologically harmless	
- high flash and boiling point with low viscosity - very good lubrication properties - good corrosion resistance - inferior cooling properties - vaporizes with residuals	- low flash and boiling point, comparatively high viscosity - poor lubrication properties - better heat removal due to evaporation heat - little residuals

Source: Fuchs Petrolub AG

However, the implementation of palm-oil based as cutting lubricant giving some advantages especially in Malaysia as known as one of the largest producer of palm oil. Palm oil-based has secondary characteristics such as biodegradability. Besides that, this vegetable oil has some advantages such as good boundary lubrication properties, excellent viscosity and compatibility with the mineral oil and additive molecules.

2.5 Vegetable Oil-Based Lubricant

Due to growing an environment concerns, vegetable oils are finding their way into lubricants for industrial applications. Refer to Ilija (2003), these oils indeed offer significant environmental benefits with respect to resource renewability, biodegradability as well as providing satisfactory performance in a wide array of applications. Synthetic ester based fluids also offer these advantages, but their cost is prohibitive for many markets. Formulating with vegetable oils present many challenges is tailoring specific products for lubrication. The notable challenges are oxidative stability, hydrolytic stabilities and low temperature properties that are innate characteristic of the triglyceride molecule.

During machining operations, heat is generated and this has adverse effects on work piece surface finish and dimensional accuracy, tool wear and life, as well as production rate. Lubricants are therefore employed in machining operations to either achieve cooling, cooling and lubrication, lubricate mainly, or minimize chip adhesion to work piece or tool. Sharma (2005) mentioned that whichever function a cutting fluid is to serve in any machining operation, it must possess some qualities, which have been identified as: high decomposition or oxidation temperature, must not be gummy, should not foam or smoke unduly, must not be a contaminant to lubricants used elsewhere in the machine. If these qualities are lacking, the cutting fluid may result in serious ecological or health issues.

To remain the performance of cutting tools during machining operation, some researcher introduce to used extreme pressure (EP) additive such as chlorine, phosphorus and sulfur such as Lawal et. al. (2007) in turning operation and Belluco and Chiffre (2007) in drilling operation. However, Sokovic and Mijanovic (2001) said that the using of conventional extreme additive such as chlorine pose a considerable to human life and environment.

Vegetables oils cannot meet most lubrication performance needs without additive, Ilija (2003). Thus, in term of concern of environmental issues, some researchers conducted the effect of antiwear additives in vegetable oils. Choi et. al. (1997) promoted the newly synthesized additive, dibutyl 3.5-di-t-butyl 4-hydroxy benzyl phosphonate (DBP) as an excellent antiwear performance compare to the conventional additive, TCP. Meanwhile. Sevim et. al. (2006) had used two additive to study oxidation and low temperature stability of vegetable oil-based lubricants which are zinc diamyl dithiocarbamate (ZDDC) and antimony dialkyldithiocarbamate (ADDC). Table 2.2 shows some additives have been used in vegetable oil.

Table 2.2 : Additives in vegetable oils

Additives	Function
Zinc diamyl dithiocarbamate(ZDDC) Antimony dialkyldithiocarbamate(ADDC)	Anti-wear and antioxidant abilities
Zinc-Dialkyl-Dithio-Phosphate (ZDDP)	Anti-wear/extreme pressure (AW/EP)
S-[2-(acetamido) thiazol-1-yl] dialkyl dithiocarbamates	Anti-wear
Palm oil methyl ester (POME)	Anti-wear
Dibutyl 3.5-di-t-butyl-4-hydroxy benzylphosphate (DBP)	Anti-wear
Butylated hydroxy anisole (BHA), Butylated hydroxy toluene (BHT), Mono-tert-butyl-hydroquinone (TBHQ), propyl gallate (PG)	Chain-breaking antioxidants
Zincdithiophosphates (DTP) Dithiocarbamates (DTC)	Peroxide decomposers antioxidant

2.6 Tool Life, Tool Failure Modes and Wear Mechanisms

Generally, tool wear can be classified by the region of the tool affected or by the physical mechanisms which produce it. The dominant type of wear in either case depends largely on the tool material. Tool wear is commonly used as a life criterion because it was directly influence tooling cost and part quality. It occurred due to the interaction between tool and workpiece or between chip and the tool. The value of flank wear is used because it influenced the surface roughness and accuracy of the machined material. Detail recommendations for the tool life are implemented in ISO 8688-2 for end milling operation as shown in Figure 2.4.

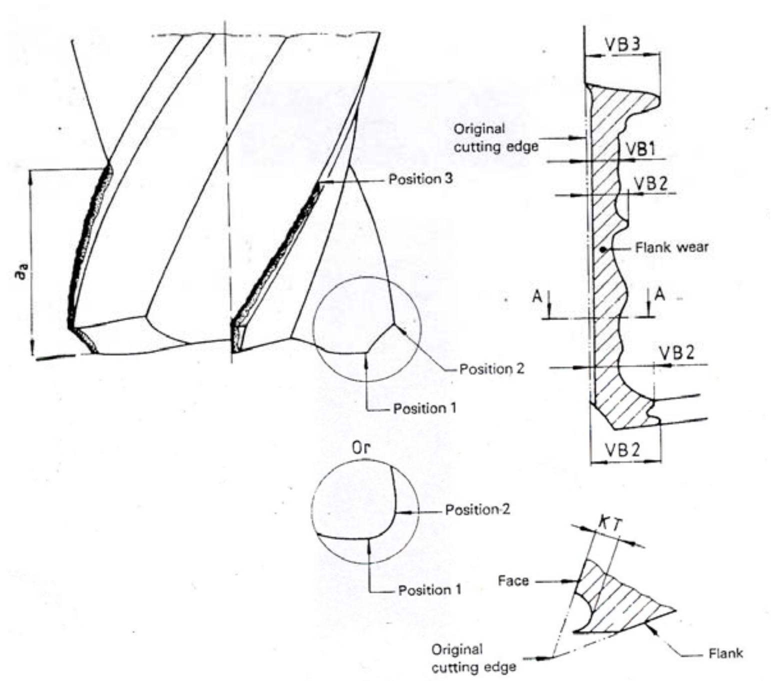


Figure 2.4 : Type of wear on end mill after ISO8688-2

In end milling, the most important type of wear is flank wear. The recommendation tool rejections for uniform and non-uniform flank wear are 0.3 mm and 0.5 mm, respectively. Nevertheless, Liao and Lin (2007) have rejected the tool when maximum flank wear in excess of 0.1 mm on any tool lips.

The physical mechanisms which produce the various types of wear depend on the materials involved and the cutting conditions, especially the cutting speed. The most significant mechanisms of wear at lower cutting speed are adhesive and abrasive wear.

CHAPTER 3

METHODOLOGY

The purpose of this research is to evaluate the feasibility of vegetable oil based palm oil as a cutting lubricant through the use of minimum quantity lubricant (MQL) during end milling of hardened stainless steel. The performance of coated carbide tools when end milling 'STAVAX ESR' stainless steel hardened to hardness of 50 HRC under minimum quantity lubrication technique in term of cutting forces, tool wear, tool life and surface roughness will be evaluated.

3.1 Machines and Equipments

The following are the machines and equipments were used throughout the experiment:

a. CNC Milling Machine

Brand/Model : MAHO MH 700S – CNC 432 Machining Centre
No of Axis : Five Axes
Working Range : 700mm × 500mm × 600mm
Spindle speed : 20-6300 rpm
Load Capacity : 100 kg

b. Machine Tools Presetter

Brand/ model : MAHO machine tool presetter

c. Tool dynometer

Brand/ Model	: Kistler Type 9625B 3 axis Dynamometer
Tool Holder adapter	: Kistler Type 9441 B
Charge Amplifier	: Kistler Type 5019 A Multi-channels
Data acquisition	: A/D Board interfacing card with DynoWare software Kistler Type 2825 D1-2, version 2.31.

d. Tool Maker Microscope

Brand and Model	:	Nikon
Magnification	:	30 X
Measuring Device	:	Incorporated Micrometer

e. Optical Microscope

Brand/model	: Carl Zeis Stemi 2000-c
Magnification	: 6.5 X-50X
Incorporated device	: SONY ExwaveHAD color Video Camera.

f. Minimum Quantity Lubricant Dispensing Systems

Model : Economiser I with 2 nozzle

g. Surface Roughness Tester

Model : Mitotuyo Portable Surface Roughness Tester

3.2 Tool Material

In this experiment, two types of solid carbide end mill with different coating will be used to milling STAVAX ESR. Every type of tool consisted two solid carbides tools (TiAlN and AlTiN).

3.3 Workpiece Material

The selected workpiece material was STAVAX ESR mould steel produced by UDDEHOLM AB. This material is premium grade stainless steel which is good corrosion resistance, wear resistance, polishable and machinable. The material always been used in making of plastic mold cavity where the good corrosion resistant increases the mold life. The high strength and hardness of the material is suitable for blow molds, extrusion molds, extrusion dies and pultrusion dies. The material for conducting the experiment was supplied by supplier in hardened state at 50 HRC. The work piece was solid block with 350 x 150 x 90 mm and 150 x 150 x 90 mm. The chemical, physical and mechanical properties of the material are shown in Table 3.1, Table 3.2 and Table 3.3.

Table 3.1 : Chemical composition of STAVAX ESR

Typical analysis %	Carbon, C	Silicon, Si	Manganese, Mn	Chromium, Cr	Vanadium, V
	0.38	0.9	0.5	13.6	0.3
Standard specification	AISI 420, Modified				

Table 3.2 : Physical properties of STAVAX ESR

Temperature	20	200	400
Density Kg/m^3	7800	7750	7700
Modulus of Elasticity N/m^2	200000	190000	180000
Coefficient of thermal expansion $^0C^{-1}$	-	11.2 x 10^{-6}	11.6 x 10^{-6}
Thermal conductivity W/m ^0C	16	29	24
Specific heat J/Kg ^0C	460	-	-

.

Table 3.3: Mechanical properties of STAVAX ESR

Hardness	50
Tensile strength N/mm^2	1780
Yield stress Rp0.2 N/mm^2	1460

3.4 Lubrication Technique and Cutting Fluid Lubricant

The minimum quantity lubrication technique is applied by using Ecomiser I MQL Dispenser System during all machining conditions. This MQL system which is the process of pulverizing a very small amount of oil (< 30ml/h) in a flow of compressed air. Then, for cutting fluid lubricant, 4 types of lubricant with difference physical properties will be tested. The using of a commercial cutting fluid (Fatty alcohol) as reference will be compared with palm oil base as alternative lubricant. Nevertheless, all types of lubricant provide wide range of biodegradability characteristic toward the 'green' machining.

1) Fatty Alchohol (as reference)

2) Palm Olein
3) Palm Olein + Additive A
4) Palm Olein + Additive B

3.5 Machining Conditions

Milling tests were conducted on a MAHO 700S CNC machining center at cutting conditions shown in Table 3.4.

Table 3.4: Cutting condition for end milling test

Tools tested	TiAlN and AlTiN coated carbides tool
End Mill Diameter	10 mm with 4 flutes
Cutting Speed (m/min)	100, 130, 160
Feed (mm/tooth)	0.05
Axial Depth of Cut	12 mm
Radial Depth of Cut	1 mm
Cutting Fluids/ Lubricants	1) Fatty Alchohol 2) Palm Olein 3) Palm Olein with additive A 4) Palm Olein with additive B

3.6 Machining Procedure

The end milling experiments will be carried out on a MAHO MH 700S CNC machining center. For the machining, two types of experiment set-ups were employed as shown in Figure 3.1 The first set-up I where workpiece material was mounted on the top of multi component force dynamometer, Kistler type 9054B for measuring cutting forces. In Set-up II, the workpiece material block was securely clamped onto the machine table for conducting the performance testing.

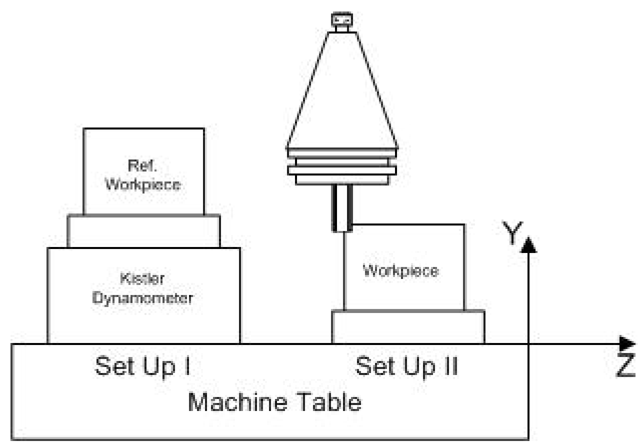


Figure 3.1: Schematic diagram of the experimental set-up

3.7 Tool Wear Measurement

Tool wear was measured using a Nikon toolmakers' microscope with magnification 30x which is connected to Nikon Digital Counter (Model CM-6F). The measurements of the tool wear according ISO-8688-2 were carried out for cutting edge at initial cutting and continuously after a particular length of cut until the end of tool life was achieved. The process was stopped when the tool wear met one of these following rejection criterions:

i. Average non-uniform flank wear (VB) ≥ 0.2 mm
ii. Maximum flank wear (VBmax) ≥ 0.4 mm
iii. Chipping ≥ 0.4 mm
iv. Fracture or catastrophic failure

3.8 Investigation on Surface Finish

A Mitutoyo portable surface roughness measurement was used to evaluate the roughness across the milled surface. Surface roughness samples were taken at one location at the end of milled surface for particular travel length of cutting tool. Three measurements were taken for each location to obtain the average surface roughness value (R_a). Analysis of the machined surface will be carried out using an optical microscope Zeiss Stemi-Axiotech which is linked to an image software KS300.

Schematic diagram for conducting the experiment for this research was shown in Figure 3.2 below.

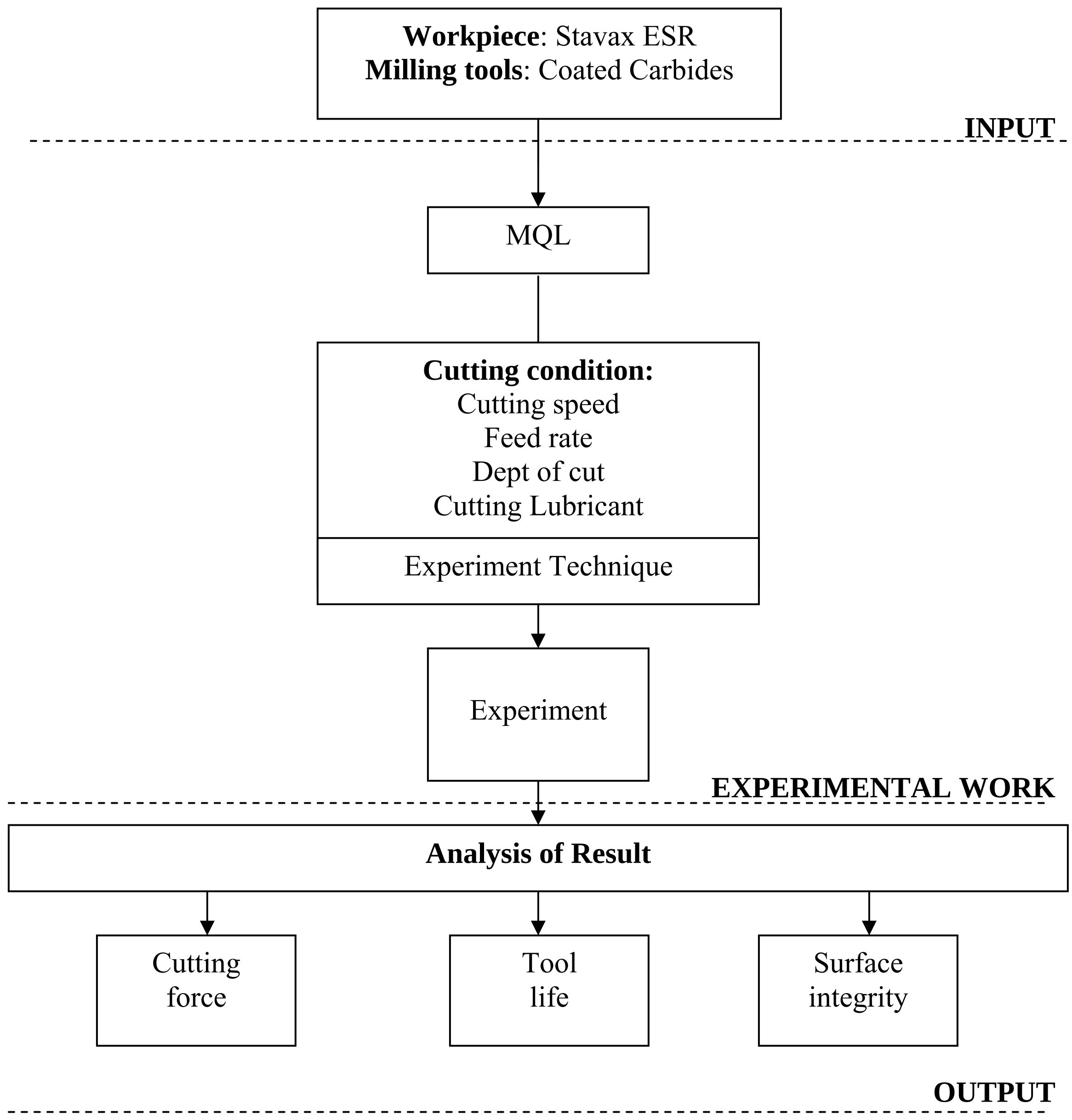


Figure 3.2: Schematic diagram of the experimental approach will be applied in this research.

CHAPTER 4

DATA AND DISCUSSION

4.1 Introduction

This section contains of the results, analyses and discussion of the tool wear, tool life, surface roughness, cutting force, and chip formation in end milling of stainless steel (STAVAX ESR) using solid carbide tool. All the cutting conditions were the same for every experiment. The coolant conditions used in this experiment were dry, flood cooling with 5% concentration Ratak Resists 68 CF2, palm oil (MQL mist), and Fatty Alcohol (MQL mist). The results were displayed in form of graphs, charts, tables and figures.

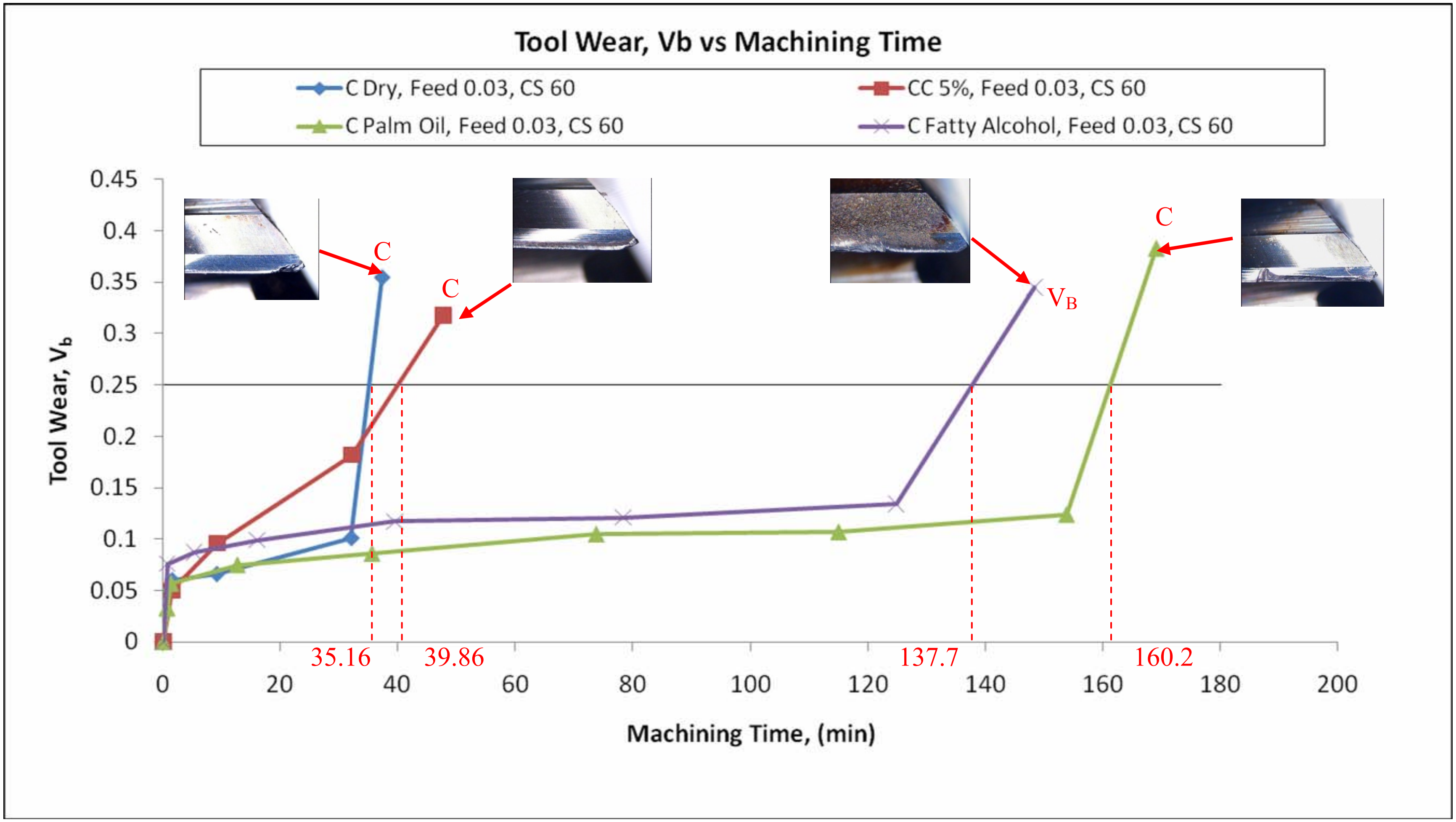


Figure 4.1: Tool wear, V_B using different types of coolant conditions

4.2 Influence of Different Coolant Conditions on Tool wear

The results obtained from the experiment have shown that the tool wear was significantly affected by the coolant conditions. Figure 4.1 shows a plot of the average flank wear against machining time for various cooling conditions. From figure 4.1, it can be seen that the tool wear progressed gradually for palm oil and fatty alcohol while for the dry and flood, the tool wear progressed rapidly. For palm oil and fatty alcohol the initial rates of tool wear shows similar trend and increase drastically after the average wear reaching 0.1mm wear land. Besides it can be noticed that the flank wear developed in three stages; primary wear phase, normal wear phase and sharp wear phase. The flank wear progressed rapidly with machining time for dry and flood cutting. However, the tool wear increased at a low rate under the palm oil and fatty alcohol coolant condition.

For fatty alcohol coolant conditions, the tools were failed due of the maximum flank wear but for the palm oil, dry and flood coolant condition, the tool failed due to chipping. The value of chipping for the palm oil tool on flute 3 (0.421) was quite large which has exceeded the tool life criteria (Chipping $\geq$ 0.3mm), hence the tool was considered failed. Figure 4.2 shows the image of wear on the tool which the tool was considered failed.

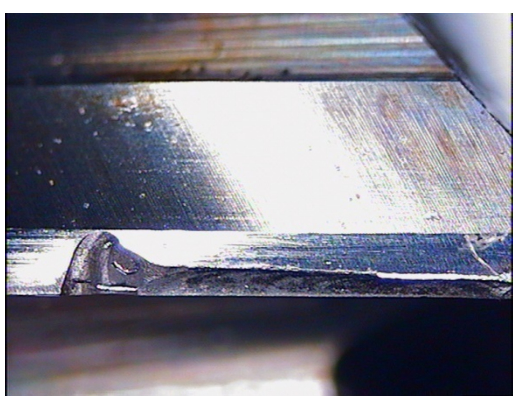
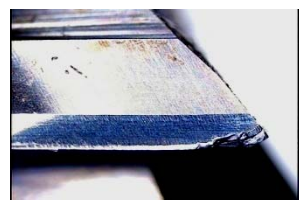
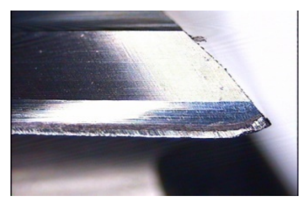
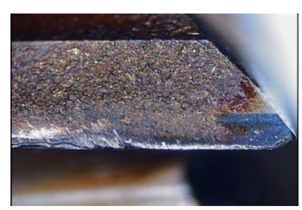
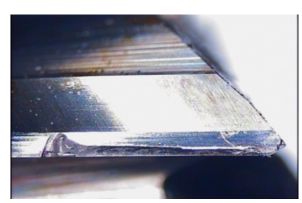


Figure 4.2: Chipping on flute 3 of the tool using palm oil coolant condition

4.3 Tool life

Tool life is the time measured when the cutting operation started until the tool reached the tool life criteria which at that time, the tool was considered fail. Tool life can be also measured in the form of cutting length. Figure 4.3 and Table 4.1 shows the tool life and images of the worn tool respectively using different coolant conditions.

Table 4.1: Tool life, cutting length and images of failed tool

Coolant condition	**Tool life (min)**	**Cutting length at tool life (mm)**	**Image of tool failed**
Dry Cutting speed 60m/min Feed rate 0.03mm/tooth	35.16	8057	
Flood Cutting speed 60m/min Feed rate 0.03mm/tooth	39.86	9099	
Fatty alcohol Cutting speed 60m/min Feed rate 0.03mm/tooth	137.74	31788	
Palm oil Cutting speed 60m/min Feed rate 0.03mm/tooth	160.27	35885	

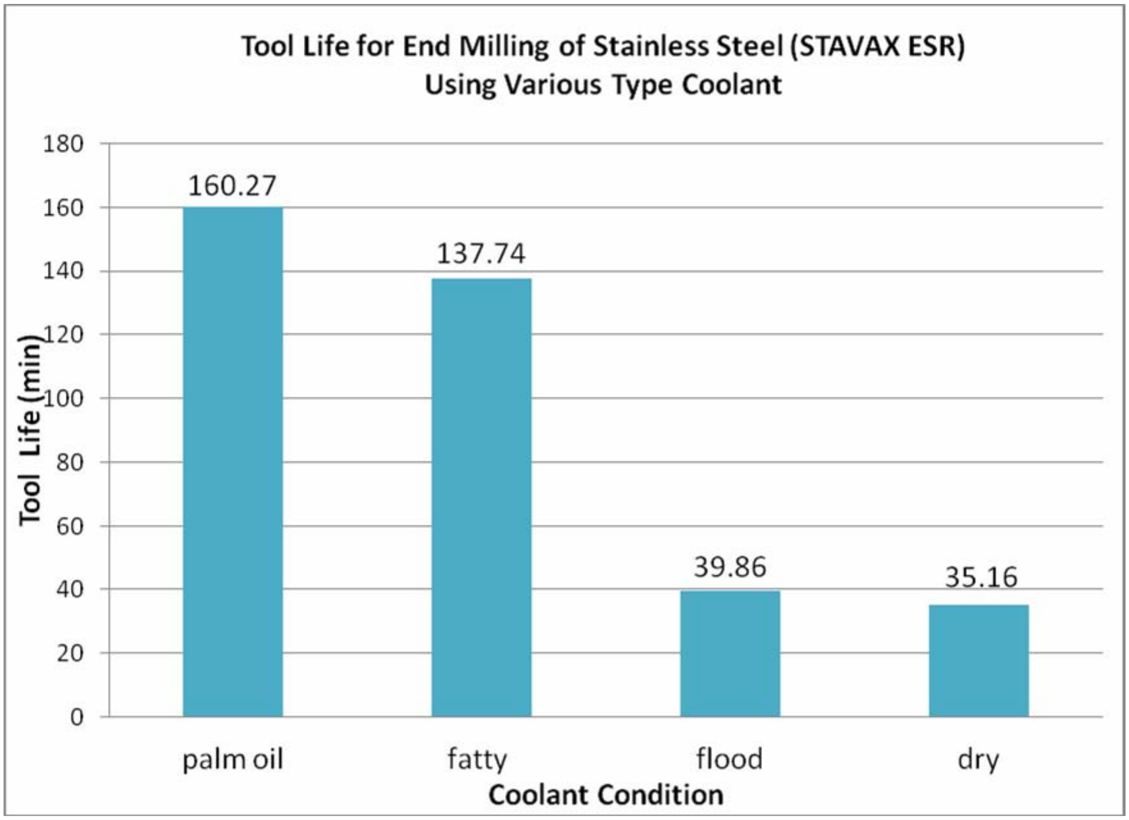


Figure 4.3: Tool life for end milling stainless steel (STAVAX ESR)

From Figure 4.3, the highest tool life recorded was when using palm oil under palm oil condition, which was 160.27 minutes followed by fatty alcohol 137.74 minutes, flood 39.86 minutes and dry 35.16 minutes. For both misting coolant condition (palm oil and fatty alcohol), the flank wear progressed slowly at the initial phase which indicates the tool that failed later than dry and flood condition.

4.4 Cutting Length

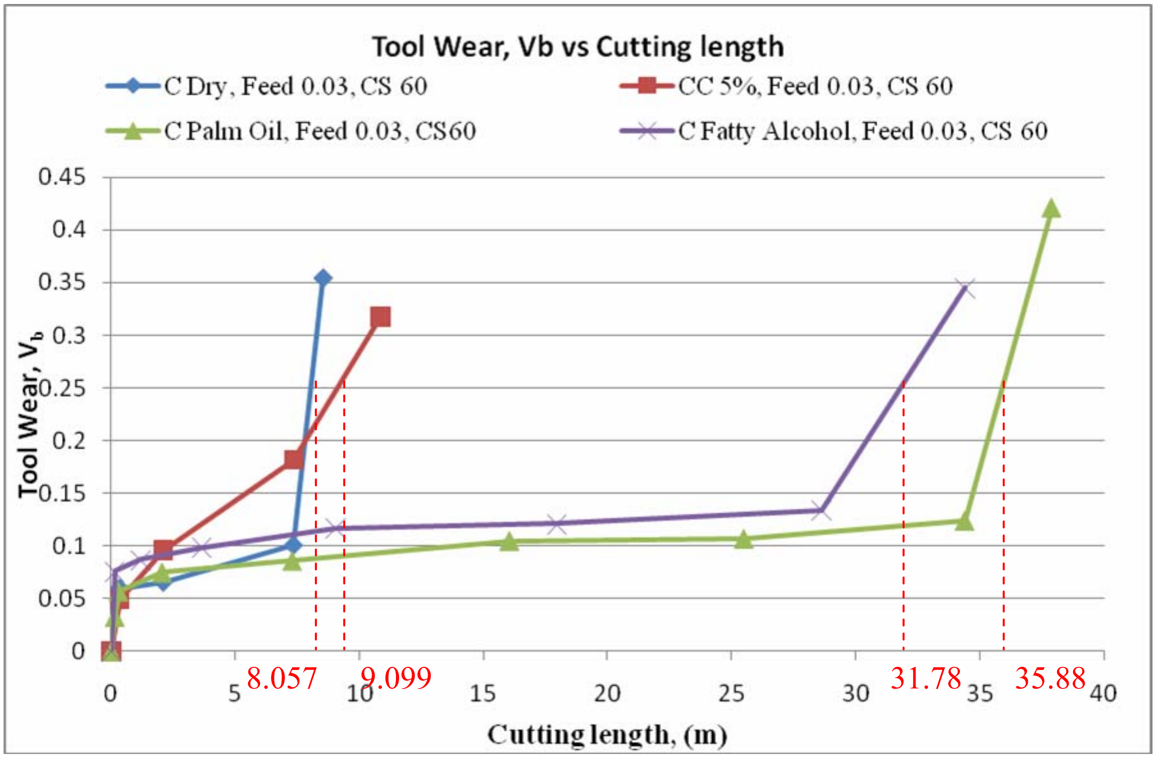


Figure 4.4: Cutting length for various coolant conditions when reaching tool life

Figures 4.4 and 4.5 show the cutting length obtained by each tool under various coolant conditions according to the tool life of the tool. The highest value of cutting length was obtained when using palm oil which is 35885mm followed by fatty alcohol 31788mm, flood 9099mm and dry 8057mm.

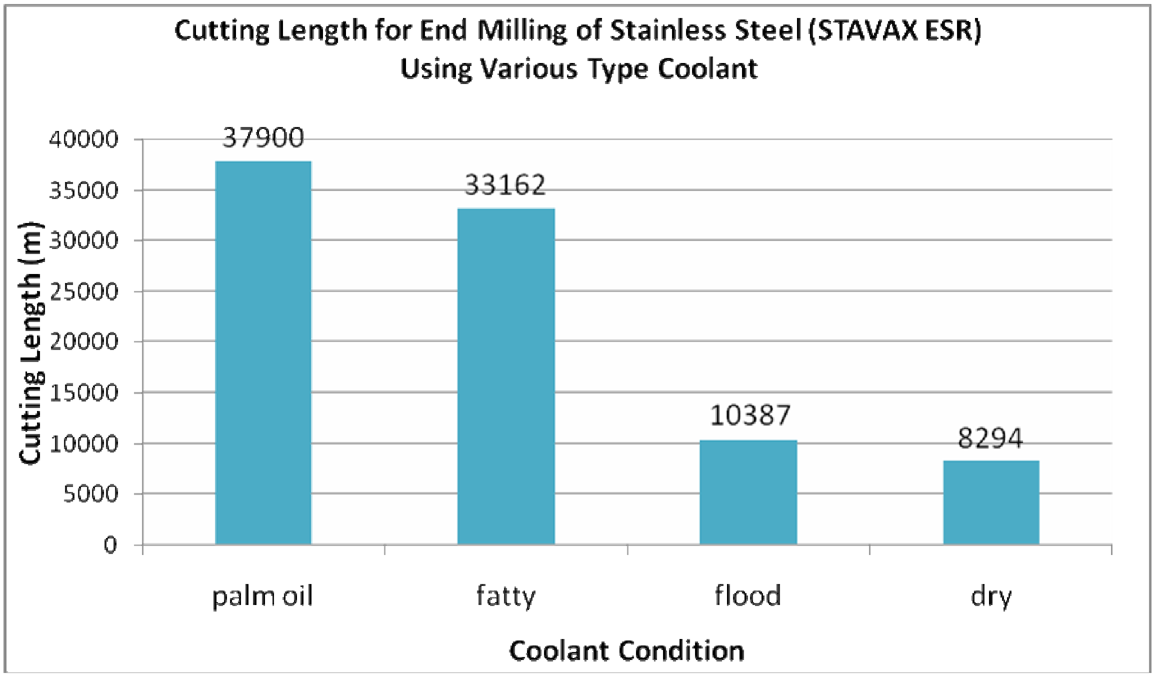


Figure 4.5: Cutting length for end milling of stainless steel (STAVAX ESR)

4.5 Surface Roughness

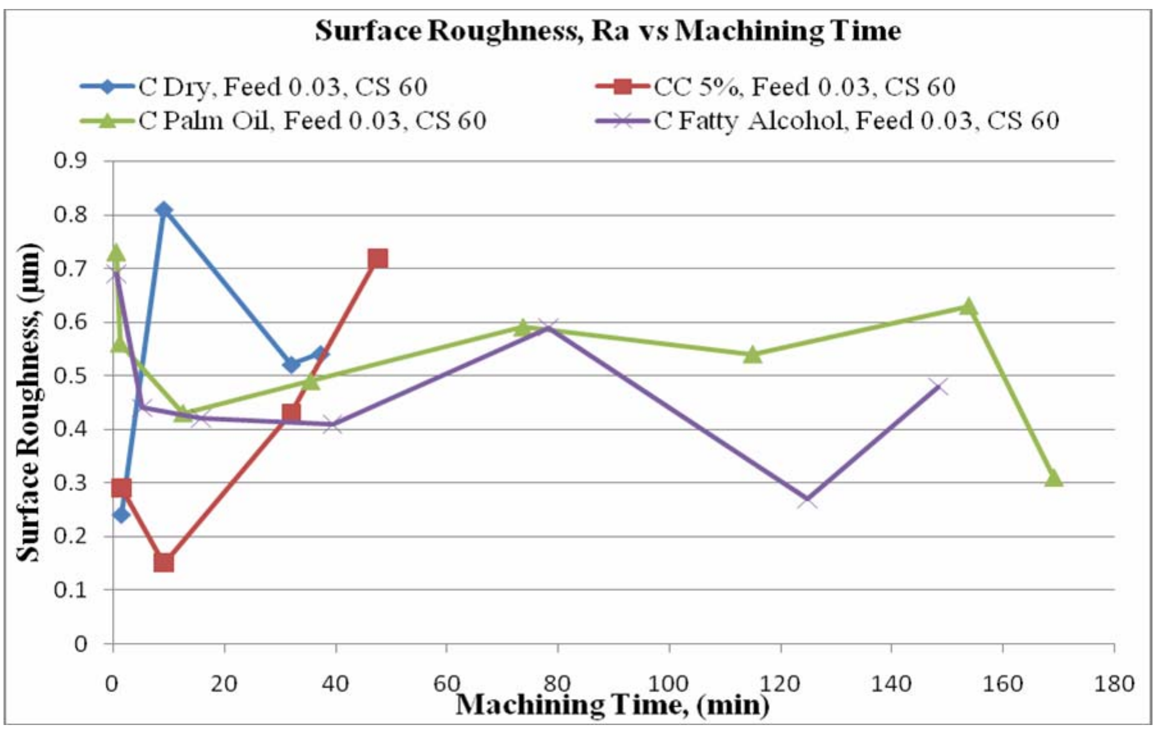


Figure 4.6: Surface roughness against machining time for various coolant conditions

Figure 4.6 shows that surface roughness of the work material are fluctuating with the machining time. The graphical relationship shown in Figure 4.6 was the average value of three measurements taken every time the experiment was stopped. Figure 4.6 also shows that the range of surface roughness value for each coolant condition varies. For example, in dry cutting, the ranges of surface roughness were between 0.24µm to 0.81µm. For flood coolant, the ranges of surface roughness were between 0.15µm to 0.72µm. With palm oil misting, the ranges of surface roughness were between 0.31µm to 0.73µm and for fatty alcohol misting, the range values of surface roughness were between 0.27µm to 0.69µm. Even as the tool wear increasing against machining time, the value of surface roughness did not increase as well as the tool wear.

As shown in Figure 4.7, for both mist condition (palm oil and fatty alcohol), the value of surface roughness at the initial stage were quite high. The respective values of surface roughness were 0.73µm and 0.69µm. But in the final stage, the value of surface roughness was lower than the value at the initial stage. The values of surface roughness were 0.31µm and 0.48µm respectively. For dry and flood coolant condition, the value of surface roughness at initial stage were quite low which the values were 0.24µm and 0.29µm respectively. But at the final stage, the values increase to 0.54µm and 0.72µm respectively.

Compared in the same period of time; from the machining started until the first tool (dry) failed, flood coolant produced the best surface roughness value. From Figure 4.6, it can be seen from the start, flood coolant recorded lower surface roughness values than the others. But, the comparison cannot be extended further as the tool life of dry cutting was short. For MQL condition, fatty alcohol recorded better surface roughness value than palm oil.

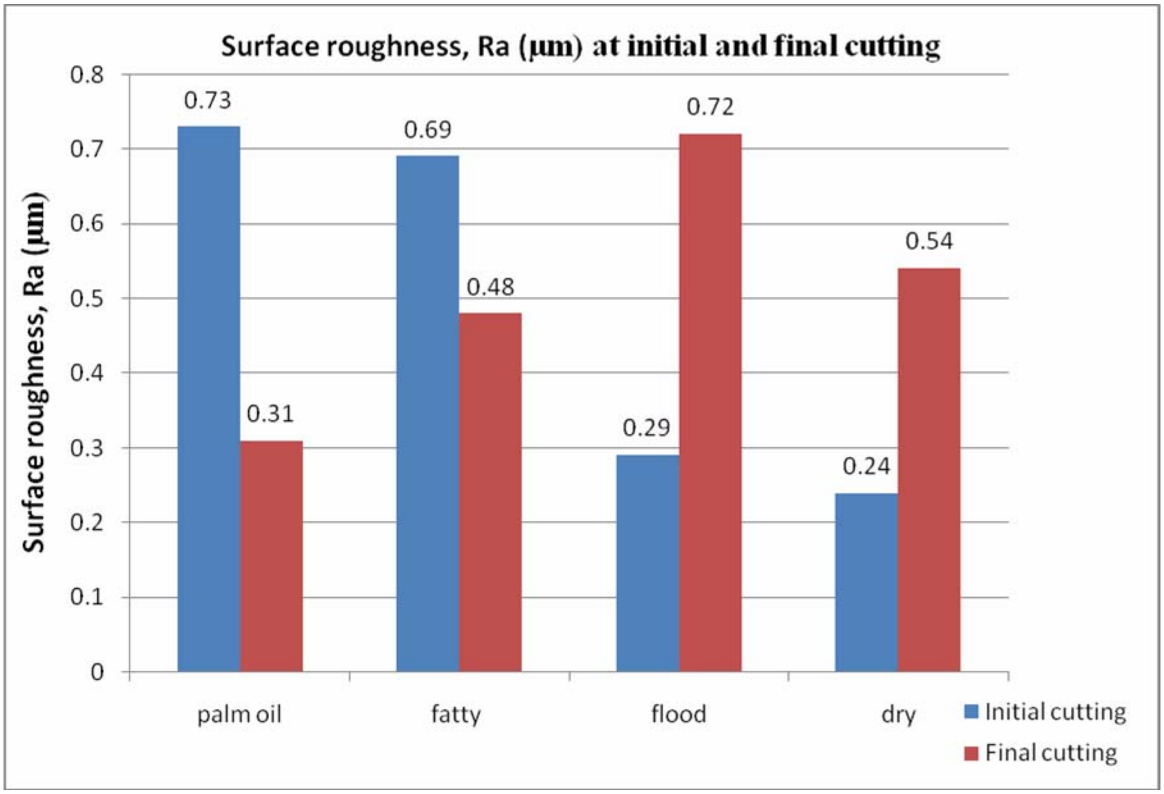


Figure 4.7: Surface roughness at initial and final cutting for end milling stainless steel

Base on the study were conducted that influence of machining conditions on surface roughness concluded that the significant effects for surface roughness were feed rate and cutting speed. The study showed that coolant concentration does not significantly affect the surface roughness. Machining at lower feed rate resulted in better surface roughness.

4.6 Chip Formation

Figure 4.9 shows the types of chip formation in end milling of stainless steel under various coolant conditions. When observed under the microscope, the chips were slight difference in the form of shape and color. At initial state of cutting, the chips were in the uniform shape for all coolant condition except the flood coolant. The non-uniform shape was observed at the edge of the chip. This non-uniform shape continued until the final stage of machining. But, for all types of coolant, the chips curled slightly from the initial stage until the final stage of machining. No flat shape chips was observed during the machining trials..

For dry and fatty alcohol coolant conditions, the chips changed its color to brown at the middle stage of cutting. This may be due to the burning effect during dry cutting. Unlike the dry and fatty alcohol, chips for flood and palm oil coolant maintained their original color (shining) throughout the machining trials.

The shape of the chips experienced changes at the middle stage of machining for fatty alcohol from uniform shape to non-uniform shape. The chips for dry and palm oil coolant were maintained at the middle stage of machining. At the final stage of machining, only the chips for palm oil coolant maintained its uniform shape. The chips shape for dry cutting, fatty alcohol and flood coolant were non-uniform at the final stage of machining. This phenomenon may be due to the effect of the worn cutting edges of the tool.

Table 4.2: Images of chips from the initial stage to the final stage of machining

	Dry	**Flood**	**Fatty alcohol**	**Palm oil**
Initial	 t = 1.53 min	 t = 1.53 min	 t = 0.65 min	 t = 0.65 min
Mid	 t = 9.16 min	 t = 9.16 min	 t = 35.54 min	 t = 39.49 min
Final	 t = 37.3 min	 t = 47.65 min	 t = 169.06 min	 t = 148.35 min

4.7 Cutting Force

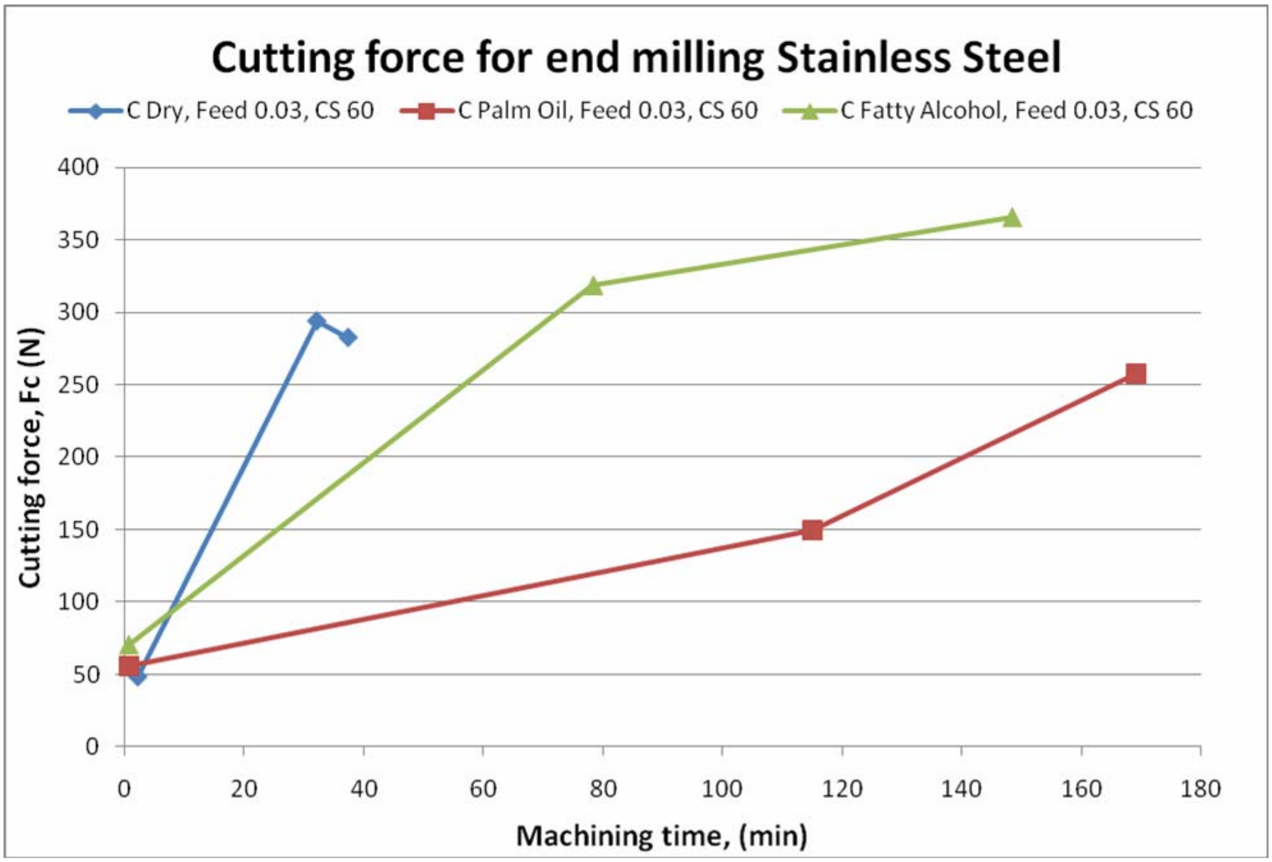


Figure 4.8: Cutting force for end milling stainless steel (STAVAX ESR) under various coolant conditions

Figure 4.8 shows the graphical relationship of cutting force against machining time of various coolant conditions. The cutting force for fatty alcohol was higher than dry and palm oil. But, for dry cutting, the cutting force increased drastically within the experiment due to the chipping effect of the cutting tool. Chipping tends to induce pressure and heat during cutting resulting in higher cutting force. This phenomenon occurred on the tool for the fatty alcohol and palm oil coolant conditions.

CHAPTER 5

CONCLUSION

Cutting fluids play a significant role in machining operations and has a great impact on the shop productivity.
The following remarks are drawn from the experimental investigations:

MQL can be regarded as an alternative to flood cooling from viewpoints of tool life for the significant improvement and surface roughness for the better achievable surface finish.

Vegetable based cutting fluid is potential substitute to fatty alcohol oil through the use of MQL technique.

Average flank wear was the dominant tool failure mode for all cooling techniques tested, with an exception for flood coolant whereby chipping occurred severely.

At the selected cutting parameters, particularly when the cutting tool was still sharp, the end-milling produced surface finish of finer than 0.8 μm Ra.

MQL gave better performance in term of tool life especially for palm oil misting. In MQL, all the fluid used is 100% oil especially for palm oil misting. This technique provides a superior lubricity and less wear on the tool because during end milling, a thin film was produced which protects the tool from further wear progress.

In MQL, fatty alcohol misting gave a better surface finish as compared to palm oil misting. The trend of surface finish between these two type of coolant was almost the same from initial cutting until the tool reached its' tool life.

MQL provide good lubrication when end milling stainless steel STAVAX ESR but has less capability of cooling effect especially for fatty alcohol misting. There is burning effect on the tool during the machining process.

It can be concluded that the main objectives of this project have been achieved which are to investigate the effect of several cutting conditions on tool life, tool wear, tool failure mode, surface roughness, chip formation and cutting force for the machinability of stainless steel (STAVAX ESR) during end milling operation using uncoated solid carbide tool.

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S. Sharif, M.A. Hisyam, R. Jamaludin and Rival, "EFFECT OF USING MINIMUM QUANTITY LUBRICATION ON TOOL LIFE IN END MILLING AISI 1050 STEEL", *Paper presented at Conference on Manufacturing and Electrical Technology (COMET 2008), 26-27 January 2008, Johor Bahru – Malaysia*

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