STUDY INTO THE EFFECT OF CRUDE PALM OIL (CPO) AS CUTTING FLUID ON THE TOOL WEAR AND CHIP FORMATION DURING MILLING OPERATIONS

By

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CERTIFICATE OF APPROVAL

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Approved by,

____

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TRONOH, PERAK.

December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except specified in the reference and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(MUHAMMAD SYUKRI BIN SEAM@SA'IM)

ABSTRACT

Stronger environmental concerns and growing regulations over contamination and pollution will increase the need for renewable and biodegradable lubricants. An annual growth rate of 7–10% for environmentally favorable lubricants is expected on the US market over the next few years compared to a rate of only 2% for the overall lubricant market. Vegetable oils are a viable and renewable source of environmentally favorable oils.

As the author's country; Malaysia is one of the world's largest palm oil supplier, it makes the idea of using the crude palm oil (CPO) as cutting fluid viable due to its easy access to the material. CPO has the criteria of a cutting fluid such as good lubricity, high in flash point and also low in viscosity. This factor makes it a good candidate to replace the standard cutting oil as it is more eco-friendly.

Therefore, the objective of this project is to measure how well the CPO perform as a cutting fluid by measuring the effects in tool wear and also the chip formation from the machining as compared to standard soluble mineral based cutting fluid.

The test was conducted with three cutting conditions which are dry, using standard soluble mineral based cutting fluid, and CPO as cutting fluid and each of the condition was ran under three different cutting speeds. The test was done on a conventional milling machine using a face mill tool with 4inserts on a tool holder.

The tool wear measurement was done in two ways: measurement of flank wear using Mitutoyo 3D Non-contact Measurement Machine and measurement of overall tool wear using high-accuracy Mettler Toledo weighing machine. The experiment has completed successfully and the results shown that CPO has the potential to replace the standard cutting fluid. The details of the experiments follow in the report.

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ABBREVIATIONS AND NOMENCLATURES

CPO – Crude palm oil

MRR – Material removal rate

AISI – American Iron and Steel Institute

SCF – Standard cutting fluid (soluble mineral oil)

ISO – International Standards Organization

BUE – Build up edge

DOC – Depth of cut

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

This project studies the feasibility of using Crude Palm Oil (CPO) as a cutting fluid in the machining operation, mainly on milling machining, as compared to standard cutting fluid, which in this project the cutting fluid used is *Solkut* cutting fluid. The feasibility study is measured by measurement of dependent variables in milling operation as an effect of changing independent variables. In this case, the study is by comparing the cutting fluids performance in terms of tool wear and chip formation. Followings are the independent and dependent variables:

Table 1: Table below shows the dependent and independent variables in machining

Dependent variables	Independent Variables
Chip formation	Tool material and coatings
Force and energy dissipated	Tool shape, surface finish and sharpness
Temperature rise in workpiece, tool and chip	Workpiece material and conditions
Tool wear and failure	Cutting speed, feed and depth of cut
Surface finish and integrity of workpiece	Cutting fluids
	Characteristic of machine tool
	Workholding and fixturing

The milling operation (specifically face milling) is conducted on three cutting conditions which are:

1. Dry machining where no cutting fluid is used during the milling operation,
2. Machining using standard cutting fluid (*Solkut*)
3. Machining using CPO as the cutting fluid

Each cutting conditions above also have been done in three different cutting speeds in order to study its behavior in different cutting speeds. The sample material used is austenitic stainless steel AISI 304, machined by PFZ grade face mill inserts. Further experimentations methodologies are explained in Chapter 3.

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

Almost all of industry sectors in present days utilize the application of lubricants to mainly reduce the undesired friction the undesired friction in their machines and materials. In fact, 35 million metric tons of lubricants were used worldwide in 2005 and the number keeps on increasing annually. From the huge amount, 85% from it are petroleum-based lubricants. If the lubricants are used and disposed inappropriately, the green Earth could end up having a serious pollution problem such as surface water and ground water contamination, soil contamination and air pollution [1]. As a consequence to the phenomenon, our sources of food, which are from mainly from agriculture sector, will also be contaminated.

Not enough with the Earth pollution, the petroleum-based oil also brings threat to human beings' health. It is reported that up to 80% of all occupational diseases of operators were due to skin contact with cutting fluid, which consists of mineral-based oil [2].

1.2.2 Significance of the Project

By reducing the percentage of application of the petroleum based lubricant, the people could help in saving the beloved planet earth. In order to reduce it, its application should be substituted with "greener" materials. Green material here is defined as a material that can be naturally degraded or in other words, biodegradable. Latest development of this sector has proven that the environment friendly vegetable oils have the potential to replace the conventional petroleum-based lubricants. The fact was said due to its environmental friendly, renewable, less toxic, and readily biodegradable material properties. By substituting vegetable oils for the petroleum-based oil, people can have a healthier life and conserve the greenness of this beloved planet.

As the author's country; Malaysia, is one of the world's largest palm oil supplier, it is the best vegetable oil candidates that is available to substitute the mineral (petroleum-based) lubricants. Also, palm oil is renewable[1] and sustainable[2] natural resources.

Therefore, this experiment is concerned to see the effect of substituting the commercial mineral-based with palm oil as cutting fluid to the cutting tool wear and the chip formation in milling operations. As the baseline of the data, the crude palm oil (CPO) is used as the basic material without any additives.

1.3 OBJECTIVES AND SCOPE OF STUDY

The objective of this project is to clarify the feasibility of crude palm oil application as the cutting fluid in milling process as an example of metal cutting process for manufacturing in terms of cutting tool wear and the chip formed from the machining.

Due to time and also cost constraints, the project scope has been limited up to certain range. The scopes of study are defined as follows:

1. Research for characteristic of Crude Palm Oil (CPO) and also milling operations (on the milling machine, cutting tool, and also cutting parameters) from several of resources ranging from books from library to internet journal and information.
2. Benchmarking studies and evaluations of CPO usage experiments on milling/machining operations.
3. Develop the appropriate experimental technique to study the effect of CPO usage as the cutting fluid for the milling operations.
4. The samples of CPO obtained will be tested on the machine by using conventional milling machine.
5. The result will be obtained from certain special facilities (i.e. 3D non-contact measurement machine) and will be analyzed.
6. Conclude the project and recommendations for further developments.

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[1]defined as a natural resource that is replaced by a natural process at a rate comparable or faster than its rate of its consumption by humans
[2] defined as a capacity to endure the consumption by the humans

CHAPTER 2

LITERATURE REVIEW/THEORY

2.1 CUTTING FLUID

2.1.1 Cutting fluid definition

Cutting fluid in machining process is a fluid that helps cooling and lubricating the contact processes at the cutting tool-chip and cutting tool-workpiece interfaces. It helps reducing the stress during machining process by changing the contact temperature, normal and shear stresses and their distributions along the interfaces.

Apart from being coolant and also lubricant, cutting fluid also helps in washing of machined parts and also become the transport for chip over significant distances such as in application of deep-hole drilling. There are five types of cutting tools which are:

1. Straight cutting oils (waterless)
2. Soluble oils (emulsions)
3. Synthetic fluids (chemical fluid)
4. Semi-synthetic fluid (micro emulsion)
5. Cryogenic fluids

Table 2: Table shows the pros and cons for each cutting fluid types

Pros	Cutting Fluid Types	Cons
• Good lubricity • Effective anti-seizure qualities • Good rust & corrosion prevention • Good for heavy duty machining	Straight cutting oil	• Poor cooling • Mist & smoke formation at high speed cutting • High initial & disposal cost
• Good cooling • Low viscosity (better wetting abilities) • Non-flammable • Non-toxic • Easy to filter out chips • Low initial and disposal costs	Soluble oil	• Low lubricity • High in rancidity • High in misting • Low stability
• Resistance to rancidity • Low viscosity (good at cooling and wetting) • Good rust protection • Little misting problem • Non-toxic • Completely non-flammable • Non-smoking • Easy to filter out chips • Biodegradable	Synthetic fluids	• Insufficient lubricity for heavy duty applications • React with non-metallic parts • Residue • pH relatively high (8.5-10.0)

Semi-synthetic cutting fluid is a special cutting fluid where it is combined from synthetic technology of cutting fluid with straight oil cutting fluid technology such as mineral oils. The fluid is developed to counter the problem of insufficient lubrication for heavy duty applications faced by synthetic cutting fluid. Even though the fluid seems to be perfect, but still it has its own drawback which is there are a whole bunch of chemistry variables that have to be considered to achieve the desired properties and functions such as lubricating, cooling and also protection against corrosion. Presently, the synthetic cutting fluid has developed and encountered the problem of lubricity. This phenomenon has made the semi-synthetic cutting fluid now getting less famous and lesser famous.

As for cryogenic cutting fluid such as liquid nitrogen, it is also utilized for special machining process and special materials such as machining of high-titanium and nickel-based alloys. The machining process has to take place at a cryogenic temperature (-196°C) because the material causes the chip formation and chip breaking to present a significant problem.

2.1.2 Cutting fluid economy

A couple of decades ago, the cost of cutting fluid in overall manufacturing process is only 3%. After developments have been made to the cutting fluid technology, and also the increment of materials costs, the percentage has increased up to 15% in present days [3].

An example quoted from Viktor P. Asthakov (2006) [4], the cost for cutting fluid used in Automotive industries in Europe reaches 16.9% of the total manufacturing cost. The number can be decreased significantly by using a much lower cost of cutting fluid such as palm oil due to its renewable and sustainable characteristic.

Followings are the chart visualizing the structure of the manufacturing cost in the European Automotive industry [5], [6]:

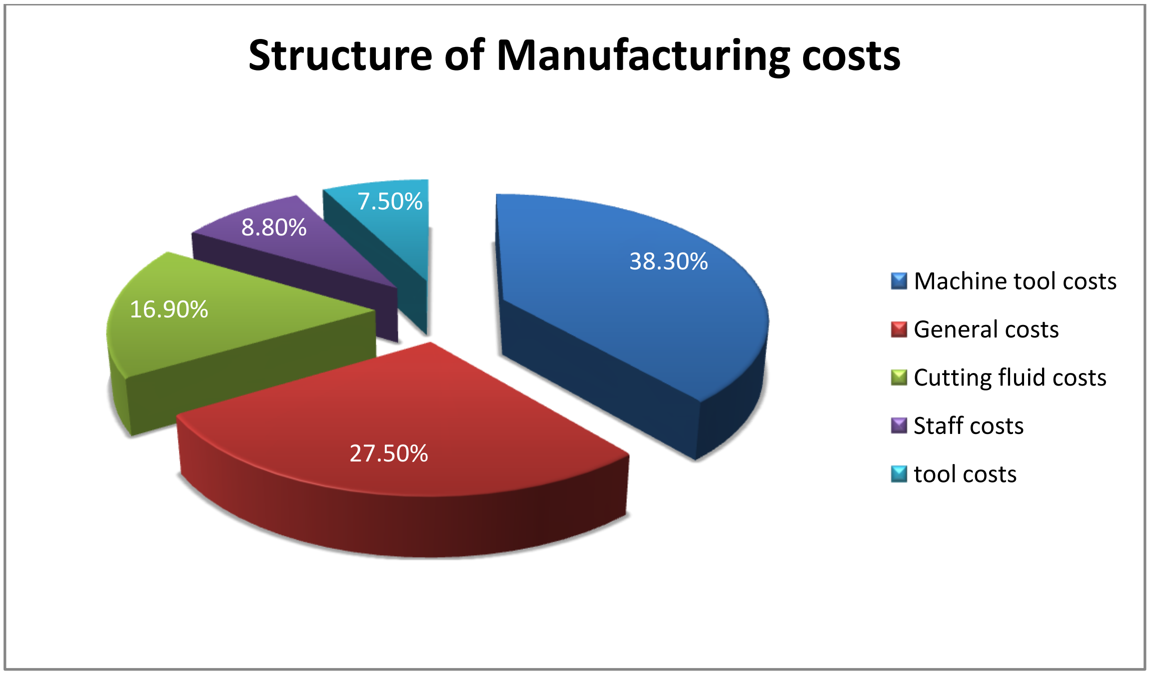


Figure 1: Figure above shows the structure of manufacturing cost in the European Automotive industry.

2.1.3 Cutting fluid test

There are various types of test to check the feasibility of using the cutting fluid to be used for machining. The test basically objected to check the lubricity, cooling and also ability to protect work material from corrosion. The various types are as follows:

1. Test on actual machine
2. Lab test
3. Rubbing test
4. Falex pin – Vee method
5. 4 balls wear test

From the tests done by people, it is concluded that the usage of proper cutting fluid (commercial) can:

1. Improve accuracy of machining
2. Reduce radius of curvature of the chip
3. Reduce tool-chip contact length
4. Increase thermal shock in interrupted cutting process such as milling.

Even though the test has been conducted, some of the test does not even resemble the actual machining condition [7]. The best way to test it is by experimenting it on the actual machine as the force, energy dissipation and also boundary conditions is perfectly the same as the actual machining process.

2.1.4 Standard Cutting Fluid Life

For standard commercial cutting fluid that is widely used in market, the shelf life for the fluid is ranging from 12 months to 24 months [8]. As for its standard life cycle, usually the manufacturer will not claim how much cycle time the cutting fluid can sustain. Normally, in normal practice for industry usage, at most frequent cutting fluid replacement rate is every 1 month and at longest is up to once per 5 months of machine run (8hours per day, 5 days per week of run) [9].

2.1.5 Cutting Fluid Application Strategy

[16] There are four basic methods of cutting fluid application in machining which are as follows:

1. Flooding

    -The most common method

    -The cutting fluid should flood the cutting interface

    -Flow rate ranging from 10L/min to 225L/min with pressure from 700kPa to 14,000kPa.

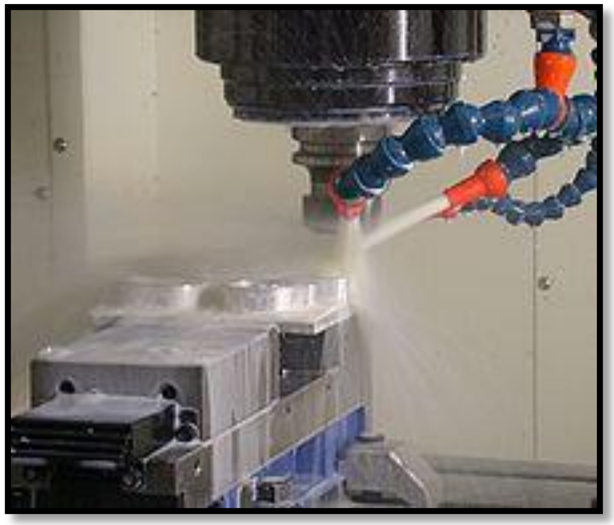


Figure 2: Figure shows the example of flooding approach of cutting fluid application

2. Mist

    -Similar concept to aerosol can.

    -Effective with water-based cutting fluid with air pressure from 70kPa to 600kPa

    -Requires good ventilation for operator safety

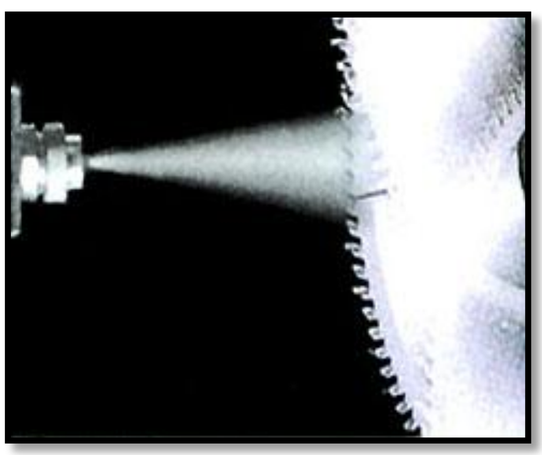


Figure 3: Figure shows the example of mist cutting fluid application

3. High-pressure system

-For high-end machining application where heat generation by the machining are very high

-Coolant is refrigerated, and then jet by nozzle to the cutting zone.

-Coolant delivered in high-pressure flow ranging from 5.5MPa to 35MPa of fluid pressure, and also acts as a very good chip breaker when the chips are very long and continuous.

4. Through the cutting tool system

-A best way to deliver cutting fluid to cutting zone but requires special tool.

-The cutting fluid is pumped out through the cutting tool directly towards the cutting zone.

2.1.6 SOLKUT 2140 cutting fluid properties [10]

Table 3: Table shows the properties for the standard cutting fluid branded SOLKUT

Properties	Description/value
Product description	Proprietary soluble metal working fluid
State	Liquid
Colour	Amber
Odour	Mild
Oxidizing	Non-oxidizing (by EC criteria)
Solubility	Soluble in water and most organic solvents
Viscosity	>40cSt (viscous)
Boiling point	>100°C
Flash point	100°C
Auto-flammability	>150°C
Vapor pressure	Very low
Relative density	0.95
pH	9.3
Evaporation rate	Slow
Viscosity test method	Kinematic viscosity in $10^{-6}m^2/s$ at 40°C (ISO 3104-3105)

2.2 CRUDE PALM OIL (CPO)

2.2.1 What is Palm Oil?

Palm oil is edible plant oil derived from the pulp of the fruit of the palm oil or scientifically called *Elaeis guineensis* [11].

Figure 4: Figure shows the palm oil tree

There are two types palm oil which are:

1. Standard palm oil (from fruit palm)
2. Palm kernel oil (from fruit kernel).

The standard palm oil is extracted from the palm of the fruit and the kernel is extracted from the kernel part of the fruit.

The crude palm oil is the palm oil which is freshly extracted from the oil palm fruit without adding any additives to its derivation.

Its properties of good in lubrication and also high very high in flash point (260°C) make it possible to be feasible to apply it as cutting fluid. The crude palm oil can be considered as straight cutting oil type of cutting fluid which is suitable for heavy duty machining application.

The oil is bio-based and also biodegradable. This will lead to easier and cheaper disposal cost and also environmental friendly. If the application of CPO as cutting fluid is proven to be very feasible, it not only can reduce disposal costs, but also save the green earth.

2.2.2 CPO Mechanical Properties [10]

Table 4: Table shows the properties for CPO

Properties	Description/value
Flash point	116.3°C
pH	4.80
Viscosity	64.69cSt

Due to the acidity of CPO, the material for workpiece used for this experiment should have high corrosion resistance such as stainless steel.

2.2.3 Reasons to use Crude Palm Oil (CPO) as cutting fluid

There are reasons that bring the idea of using CPO feasible to replace the commercial cutting fluid. The reasons are as follows:

1. CPO is natural resources that are renewable and sustainable.
2. CPO is readily available in Malaysia market
3. CPO price is cheap (as it processed locally, RM2570 per tonne metric or RM0.90 per 350g compared to RM135 for 350g for commercial cutting fluid)
4. CPO is good as lubricant (bio-based oil)
5. CPO is biodegradable, unlike mineral-based cutting fluid
6. CPO is high in flash point (260°C), thus less possibility to self ignite during machining
7. CPO is moderate in viscosity (good in wetting)
8. CPO contains no water derivative (corrosion prevention)

Therefore, if the project can be found that the application of CPO as cutting fluid in machining can improve the tool life and reduce cutting stress (characterization in chip formation), the idea could be very feasible to be implemented in future. Malaysia as the main manufacturer of CPO also can get the benefit from this findings.

2.2.4 Crude Palm Oil Allocation

According to Y.M. Shashidhara and S.R. Jayaram [1], 35 million metric tons of lubricants were utilized for manufacturing in 2005.

According to Tony Liwang [12], in this year of 2010, it is predicted that the world will produce 35.10 million tons metric of palm oil and it keeps on increasing with 4.1% of growth up to the year of 2020.

From the huge annual production rate, 80% of the palm oil will be processed for food application and the rest is for other purposes.

If this 20% of world’s palm oil is utilized specially for replacing the manufacturing cutting fluid, 20% of mineral based cutting fluid utilized worldwide can be replaced by this eco-friendly palm oil. The number can be increased when the idea is proven to be working and thus, much more investments and also researches can be done to much further improve this idea towards the greener Earth.

2.3 WORKPIECE MATERIAL PROPERTIES

Material used for workpiece: AISI 304 Austenitic Cr-Ni Stainless Steel

The material has a better corrosion resistance than type 302. It has a high in ductility, essentially non-magnetic, less carbide precipitation in the heat affected zone during welding due to low carbon content and also has a lower susceptibility to intergranular corrosion. Density = 8.00g/cm^3

Table 5: Table shows the AISI304 stainless steel properties

Properties	Value
Hardness, Brinell	123
Hardness, Vickers	129
Ultimate tensile strength	505MPa
Yield strength	215MPa
Elasticity modulus	193-200GPa
Poisson ratio	0.290
Shear modulus	86.0GPa
Thermal conductivity	16.2W/m-K
Melting point	1400-1455°C

2.4 TOOL WEAR

2.4.1 Tool wear

There are four main types of tool wear, which are:

1. Flank wear
2. Crater wear
3. Nose wear
4. Notch/groove wear (Depth of Cut line)

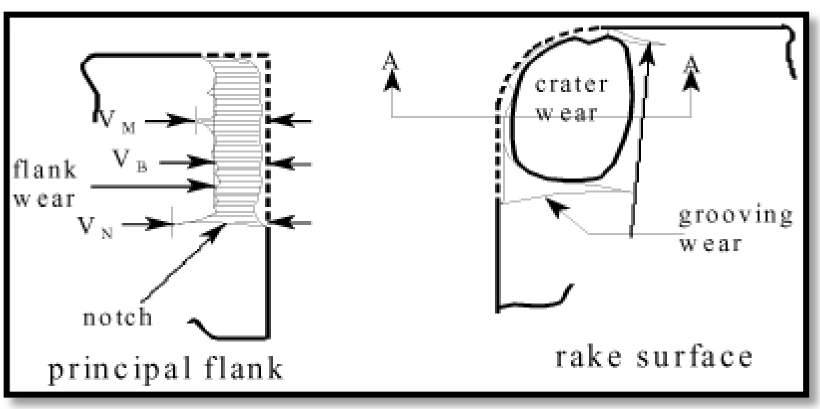


Figure 5: Figure shows the tool wear visualization

The cutting fluid used expectedly should give a lesser tool wear characteristic compared to machining without using any cutting fluid due to better lubrication and cooling. The types of tool wear will be analyzed from the results of the tests to be conducted later as the analysis of the result.

Replacing commercial cutting fluid with CPO could yield either better or worse result in terms of tool wear and chip formations. If the results are better, it is a good opening towards further development of it. Not only our beloved country can benefit from the findings, but also the whole wide world due to its greener characteristic.

Factors causing the tool wear are as follows:

1. High contact temperatures at the tool chip-chip-workpiece interfaces which lead to softening of the tool material and promote diffusion and chemical (oxidation) wear
2. High contact pressures at these interfaces and sliding of fresh, not previously encountered work material layers promote abrasive and adhesion wear
3. Cyclic nature of the chip formation process leads to the temperature and cutting force fluctuations at the tool-chip-workpiece interfaces, which can cause cracking due to thermal fatigue

The tool wear can be reduced if the factors above are countered. These factors can help formulating the additives to be added with CPO for future development.

2.4.2 Tool Wear Measurement Standards: ISO 8688-1:1989

With accordance to standards from International Standards Organization on face milling tool wear testing, specifically on ISO8688-1:1989, the multipoint cutting tool wear is identified by the average wear of all of the inserts wear. Unlike single-point cutting (such as lathe, according to ISO3685:1993) the tool wear can be easily identified due to only one insert that is used during the machining.

Therefore, in this experiment, the plots that are visualized in the results section are the average tool wear out of the inserts used per machining condition.

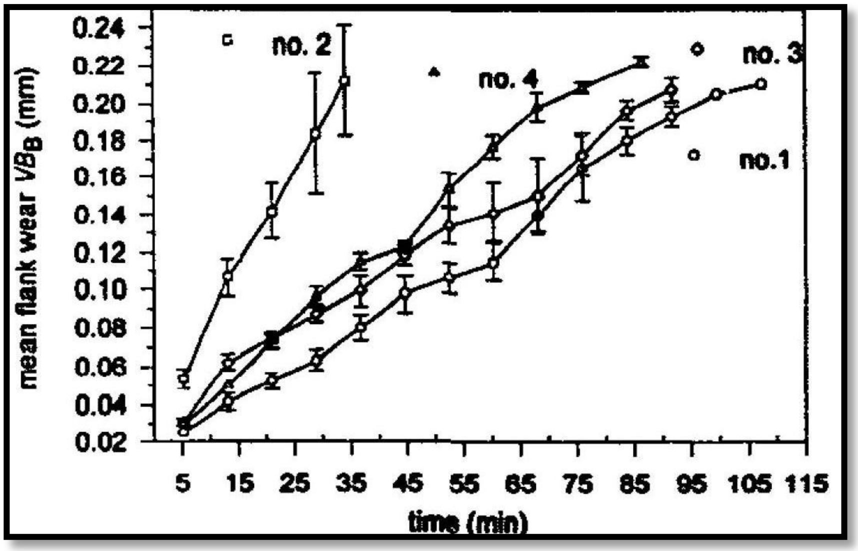


Figure 6: Figure shows an example of test result according to the particular ISO standards [13]

2.4.3 AISI 4140 Face Milling Using Vegetable Oil

By using AISI 4140 stainless steel as the workpiece, Jie Gu, Gary Barber, Simon Tung and Ren-Jyh Gu [14] claimed that by using standard cutting fluid, the tool will achieve a flank wear of 0.1mm after machined 60m length of the particular material with a depth of cut (DOC) of 0.25mm and cutting speed of 48m/min. In addition, Wisley Sales, Marcelo Becker, Clovis S. Barcellos, Janes Landre Jr., John Booney, and Emmanuel O. Ezugwu [15]claimed that by using vegetable oil as the cutting fluid, the insert will have a flank wear of 0.1mm after machining the particular material of length of 14m with a depth of cut of 1.0mm and cutting speed of 250m/min.

In order to compare both cases quantitatively, the material removal rate (MRR) of both cases are calculated. Followings are the calculations:

$$MRR = Vdl$$

where:

V = cutting speed
d = depth of cut
l = length of cut

Therefore, for the milling using standard cutting fluid:

$$MRR = 48m/min \times 0.00025m \times 60m$$

$$MRR = 0.72m^3/min$$

As for milling using vegetable oil:

$$MRR = 250m/min \times 0.001m \times 14m$$

$$MRR = 3.5m^3/min$$

Therefore, it is shown that, the MRR has increased by:

$$\%increment = \frac{3.5m^3/min - 0.72m^3/min}{0.72/min} \times 100\%$$

$$\%increment = 386.11\%$$

From this literature, it is shown that vegetable oil has a high potential to replace standard cutting fluid to be used as cutting fluid during machining.

2.4.4 Tool Life Equation

Tool life (usually in minutes) is important parameters to ensure the machined product's quality especially on dimensional accuracy and surface quality.

F.W. Taylor has done the study on machining steels and he came out with approximation relationship between the cutting speed and the time to develop a certain flank wear land.

The equation is denoted by follows:

$$VT^n = C$$

V is the cutting speed, *T* is the time for the flank wear to develop to a certain measurement, *n* is the exponent (tool, workpiece material and cutting condition dependant) and C is the constant.

Cutting speed is the most important process variable associated with the tool life, followed by depth of cut and feed.

2.5 CHIP FORMATIONS [16]

Four types of mainly-produced chip [16]:

1. Continuous chips
2. Build-up edge
3. Serrated/segmented chips
4. Discontinuous chips

As for milling operations, the continuous chips cannot occur as it is an interrupted cutting process where the cutting tool does not touch the workpiece all the time during machining process. The types of chip formation will be identified during the test being conducted as the analysis of the result.

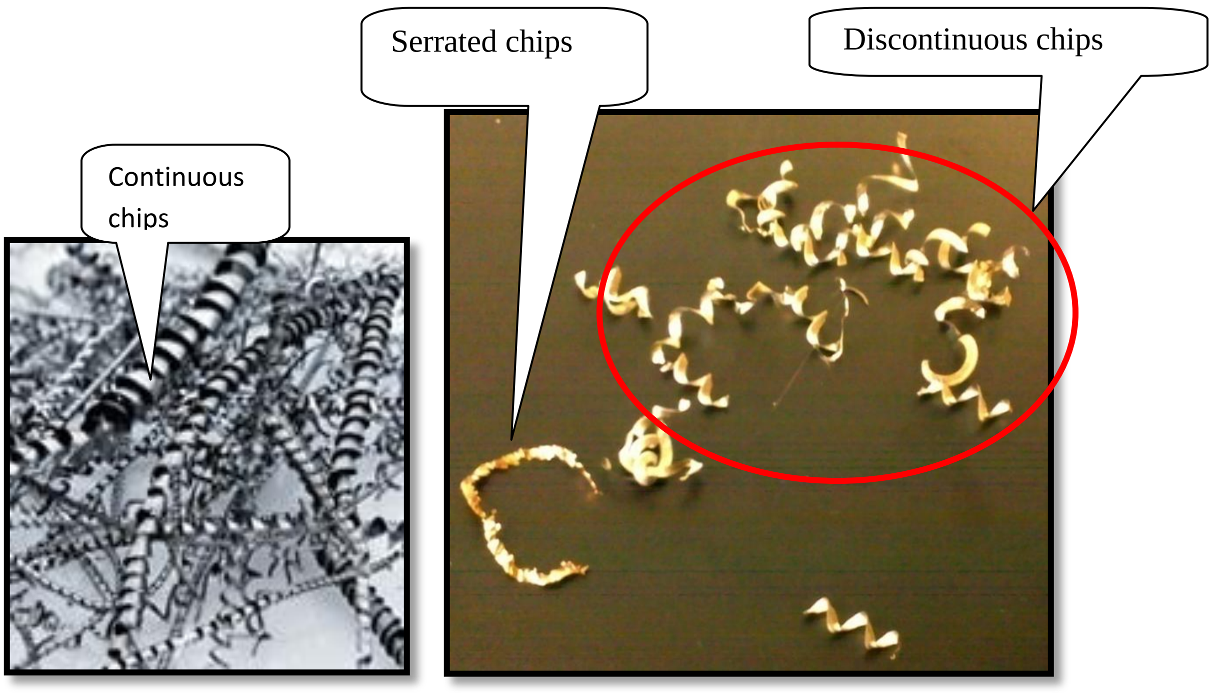


Figure 7: Figure above shows the examples of chips produced in machining

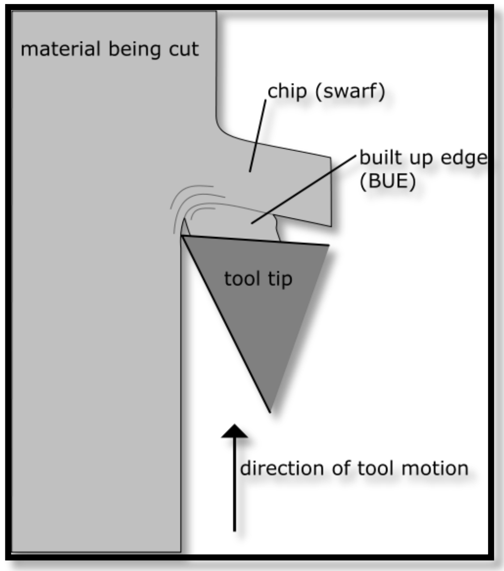


Figure 8: Figure above shows how the built-up edge (BUE) chips are produced [17]

If the chip formation is found to indicate that there is lower stress in cutting by using CPO as cutting fluid compared to commercial cutting fluid, it is proven that CPO is a feasible idea to replace commercial cutting fluid. If the result is vice versa, there is still room for improvement such as adding additives to its derivatives.

2.6 MINIMUM QUANTITY LUBRICATION (MQL) IN MILLING OPERATIONS

S. Thamizhmanii, Rosli and S. Hassan [18] proven from their experiment that MQL of their respective milling parameters is at best with 37.5ml/hour. The authors also added that the MQL application yields quite a number of advantages such as:

- Provides lubrication on machines set up for flood or high-pressure, high-volume coolant delivery and recovery
- Reduces mist and spray, therefore, offering an attractive alternative on unenclosed machines like a typical tool room mill or lathe
- Reduces or eliminates problems associated with thermal shocking of the cutting tool

- MQL technique produces a significant role in terms of reducing cutting temperature between tool-work piece interfaces.
- MQL can reduce the corner and flank wear more effectively than a solution type of cutting fluid.
- Particularly well suited for tools and operations either generated heat or abrasion to the flank of the tool is the major players to tool failure.
- Reduces both cost of buying and disposing of conventional

The authors measured the tools flank wear by using tool makers' microscope and followings are few of the results yield from the respective experiments:

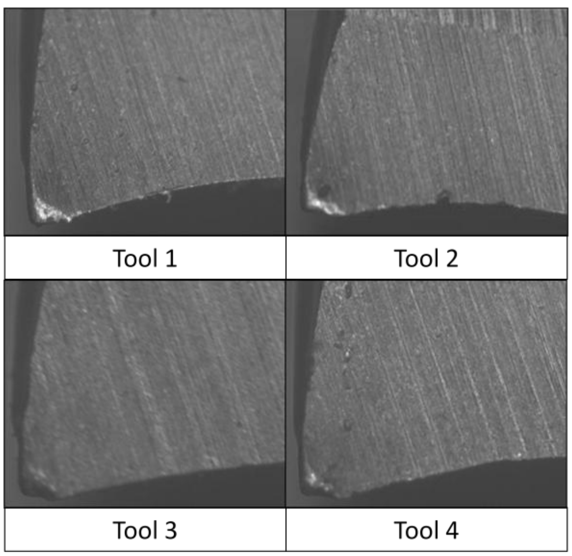


Figure 1: Figure above shows the milling process with MQL

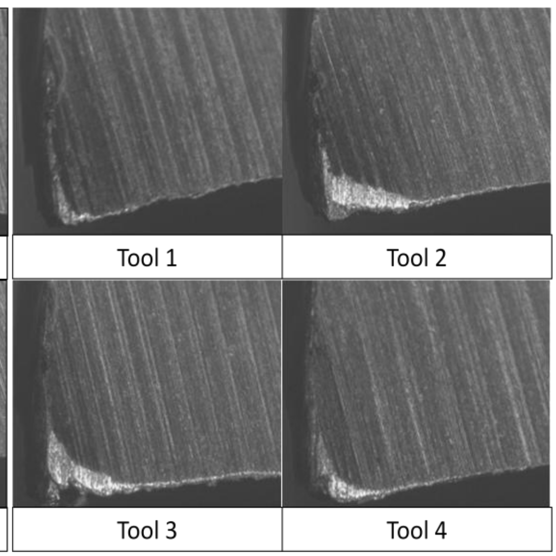


Figure 2: Figure above shows the dry milling process

From the experiment, the author concluded that MQL technique offers better results compared to dry cutting.

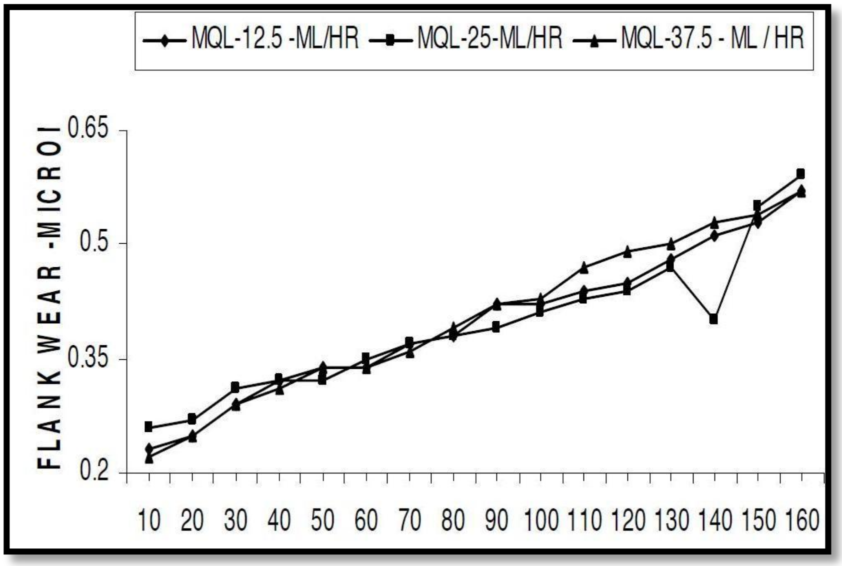


Figure 9: Figure above shows plot of the tool wear (flank) versus machining time (minutes). The tool measurement using toolmakers microscope

From the above plot, it can be concluded that MQL application is optimum at 37.5ml/hr of flow rate.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 RESEARCH METHODOLOGY

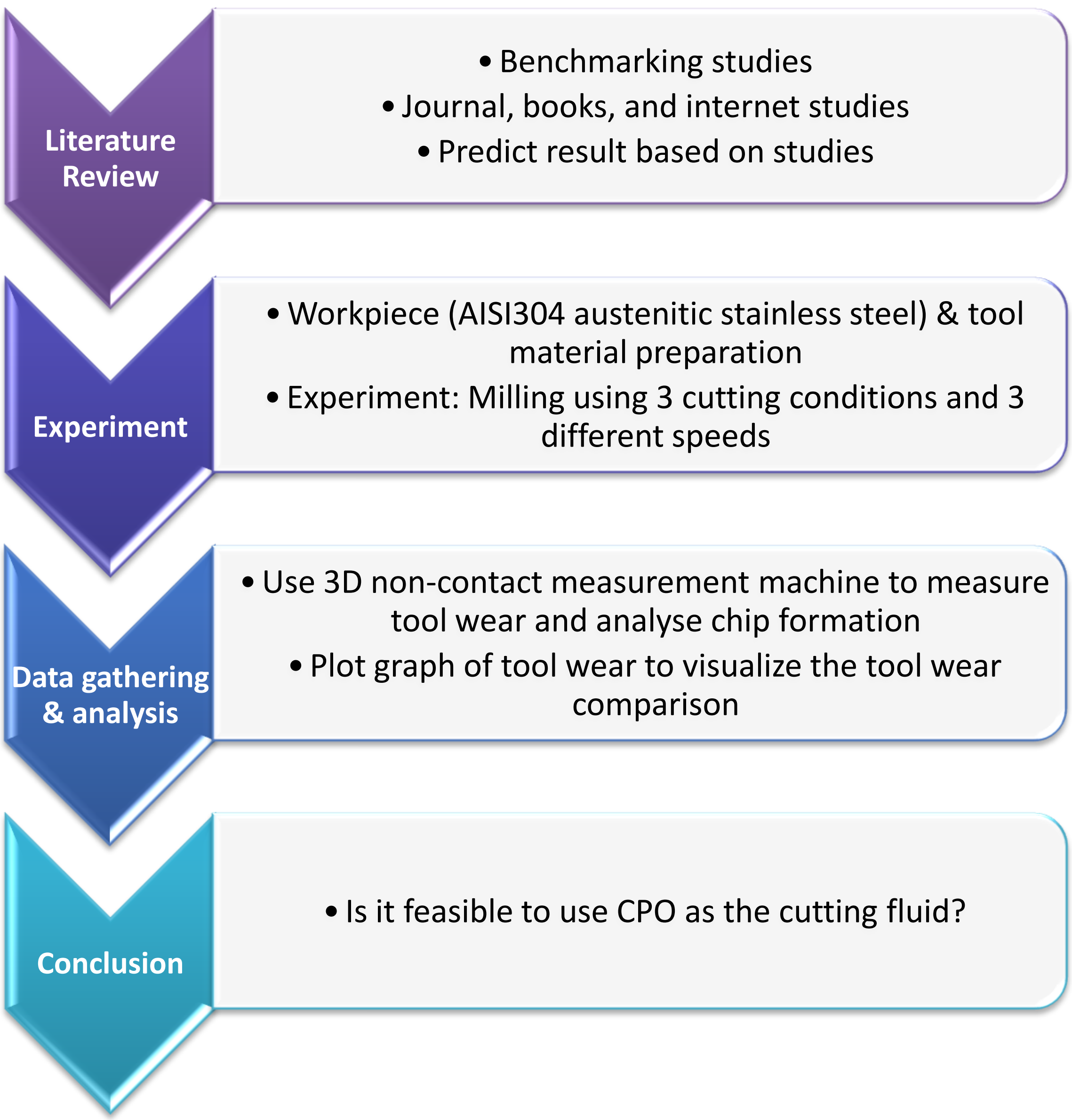
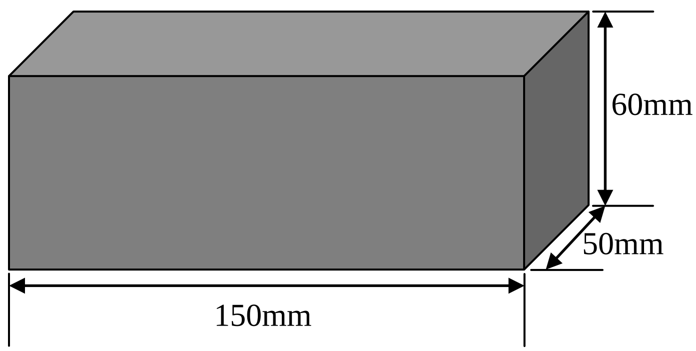


Figure 10: Figure shows Research methodology for the project

3.2 CUTTING PARAMETERS CALCULATIONS

In this experiment, the workpiece material is selected to be stainless steel due to the acidity behavior of CPO. Therefore, AISI304 austenitic stainless steel is selected to be the workpiece material due to availability of the material in the market.

The workpiece dimensions are determined as follows:



Followings are the justification for the dimension value identification:

Table 6: Table shows the dimension value selection justifications

Dimension part	Justification
Length (150mm)	Determined by the workpiece holder length on the milling machine
Width (50mm)	Determined 10mm smaller than the cutter diameter (cutter diameter=60mm) in order to ensure the whole machining face are cut during a particular milling operation
Height (60mm)	Determined by the total material removal rate and the workpiece holder height

The cutting parameters are initially selected according to the general recommendations of cutting parameters for milling operations. The general recommendations of milling parameters are as follows:

General Recommendations for Milling Operations					
Material	Cutting tool	General-purpose starting conditions		Range of conditions	
		Feed mm/tooth	Speed m/min	Feed mm/tooth	Speed m/min
Low-carbon and-free machining steels	Uncoated carbide, coated carbide, cermets	0.13–0.20	120–180	0.085–0.38	90–425
Alloy steels					
Soft	Uncoated, coated, cermets	0.10–0.18	90–170	0.08–0.30	60–370
Hard	Cermets, PcBN	0.10–0.15	180–210	0.08–0.25	75–460
Cast iron, gray					
Soft	Uncoated, coated, cermets, SiN	0.10–10.20	120–760	0.08–0.38	90–1370
Hard	Cermets, SiN, PcBN	0.10–0.20	120–210	0.08–0.38	90–460
Stainless steel, Austenitic	Uncoated, coated, cermets	0.13–0.18	120–370	0.08–0.38	90–500
High-temperature alloys Nickel based	Uncoated, coated, cermets, SiN, PcBN	0.10–0.18	30–370	0.08–0.38	30–550
Titanium alloys	Uncoated, coated, cermets	0.13–0.15	50–60	0.08–0.38	40–140
Aluminum alloys					
Free machining	Uncoated, coated, PCD	0.13–0.23	610–900	0.08–0.46	300–3000
High silicon	PCD	0.13	610	0.08–0.38	370–910
Copper alloys	Uncoated, coated, PCD	0.13–0.23	300–760	0.08–0.46	90–1070
Plastics	Uncoated, coated, PCD	0.13–0.23	270–460	0.08–0.46	90–1370

Figure 11: Figure above shows the general recommendations of cutting parameters for milling operations [16]

The insert to be used has been selected with tools with PFZ grade. This PFZ grade tool is coated with TiN-TiC-TiN by Chemical Vapor Deposition technique which has a coating thickness of 3.0 to 5.0 microns. This high-grade tool performs well in milling stainless steel, nickel-based alloys, ductile iron, and even titanium with or without cutting fluid application. Therefore, this tool is very suitable to be used in this experiment because this experiment involves milling stainless steel at high-speed milling without using any cutting fluid.

The milling machine that used in this experiment is using a 60mm-diameter, 4-tooth face mill tool holder. By benchmarking other experiments done in journals, the depth of cut is set to 0.1mm. According to recommendations in Figure 10, the starting cutting speed selected is 120m/min. The other two cutting speed values are then increased with increments of 50m/min, which are 170m/min and finally 220m/min. From this value, the spindle speed required to be set in the milling machine are calculated as follows:

$$Spindle\ speed, N = \frac{V}{\pi D_0}$$

Where,

V = Cutting speed

D_0 = Cutter diameter

Therefore,

$$Spindle\ speed, N = \frac{120m/min}{\pi 0.06m}$$

$$Spindle\ speed, N = 636.62rev/min$$

In the Excel FU281 Universal Milling Machine, the preset input of spindle speeds are as follows:

Figure 12: Figure shows the preset input of spindle speed in Excel FU281 Universal Milling Machine

NOTE: The values in Figure 12 are in RPM unit.

The values in Figure 12 are tabulated as follows for easier reference:

Table 7: Table shows the list of spindle speed available on the milling machine

50RPM	400RPM	200RPM	1600RPM	100RPM	800RPM
40RPM	315RPM	160RPM	1250RPM	630RPM	630RPM
63RPM	500RPM	250RPM	2000RPM	125RPM	1000RPM

Therefore, the nearest value to the previously calculated spindle speed, 636.62RPM is 630RPM. The other two speeds detailed calculations can be referred in Appendix A-1.

With reference to the general recommendations for milling machining, the feed recommended ranges from 0.08mm/tooth to 0.38mm/tooth. Therefore, the feed selected is 0.08mm/tooth as per recommended and is kept constant. Followings are the calculations for the feed rate value to be set on the milling machine:

$$Feed\ rate, v = fNn$$

Where

f = feed as per recommended

N = Spindle speed as per calculated

n = number of tooth

Therefore,

$$Feed\ rate, v = 0.08mm/tooth \times 630RPM \times 4tooth$$

$$Feed\ rate, v = 201.6mm/min$$

Followings are the available preset feed rate on the machine:

Figure 13: Figure shows the preset input for the feed rate of the machine

Table 8: Table shows the list of available feed rate on the milling machine; units are in mm/min

200	315	500	400	630	125	100	160
25	40	63	50	80	16	12.5	20

Therefore, the nearest value of feed rate available on the milling machine with the calculated value of feed rate, 201.6mm/min is 200mm/min.

The other two feed rate detailed calculations are available in Appendix A-2.

As for the material removal rate (MRR), followings are the particular calculations:

$$MRR = wdv$$

Where

W = width of the workpiece

d = depth of cut

v = feed rate

Therefore,

$$MRR = 50mm \times 0.1mm \times 200mm/min$$

$$MRR = 1000mm^3/min$$

The detailed calculations for all of the MRRs are available in Appendix A-3.

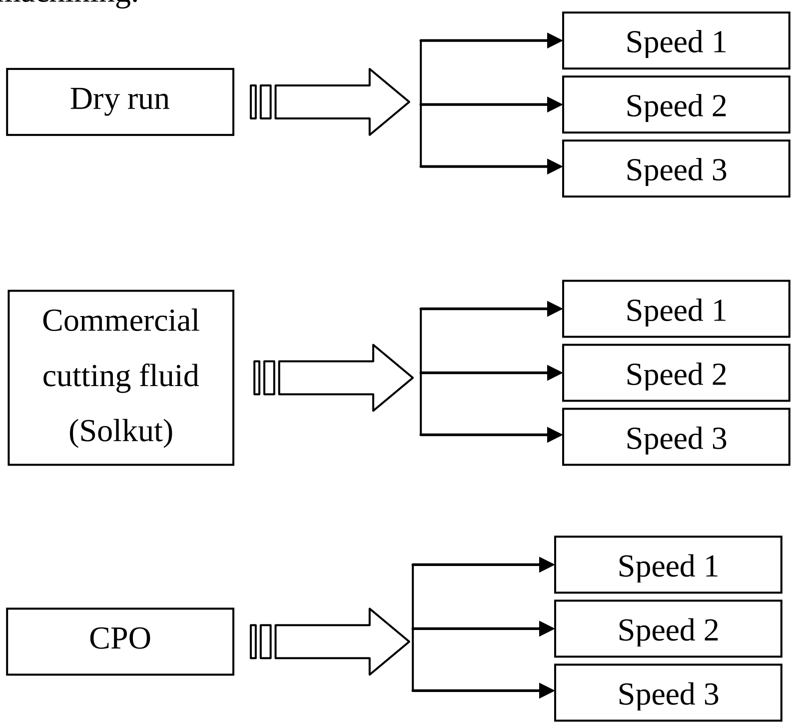
After all of the calculations done, followings are the list of the machining parameters involved during the milling operations:

Table 9: Table shows the cutting parameters used during the experiments

Cutting speed (m/min)	Spindle speed (RPM)	Feed rate (mm/min)	MRR (mm^3/min)
120	630	200	1000
170	800	315	1575
220	1250	400	2000

3.3 EXPERIMENT METHOD

The experiment will be conducted with accordance to following variables with 5 minutes of machining interval in order to examine the tool wear behavior during the machining:



Due to insufficient of time, only Speed 1 that is able to be done with 5minutes interval. Others are done straight 25minutes of milling in order to gain a tool wear plot.

The steps are as follows:

1. Fix the material on to the vice of the milling machine and load the cutting tool (insert) to be examined.

2. Set the tool to the starting point of cut with 0.1 mm depth of cut

3. Set the spindle speed as 630RPM and feed rate of 200mm/min.

4. Direct the cutting fluid nozzle towards the cutting zone (not for dry machining).

Figure 14: Figure shows during milling operation were done. Left – Using CPO as cutting fluid

5. Switch on the cutting fluid pumping system.
6. Start milling for 5minutes.
7. Bring the material to the safe location, unload the cutting tool insert and load with new inserts.
8. Collect the chip into a collector case and label appropriately.
9. Examine the chip and inserts collected from the tests under the 3D non-contact measurement machine.
10. Repeat Step 1 to 9 is for another 5minutes until the cumulative time is 25 minutes.
11. Repeat Step 1 to 9 is for 800 and 1250RPM of spindle speed and 315 and 400mm/min of feed rate, respectively.
12. After completed, repeat step 1-10 for dry cutting condition (without cutting fluid) and also with CPO cutting fluid.
13. Tabulate and plot the data obtained from the measurement under 3D non-contact measurement machine accordingly.

NOTE:

1. Filter the CPO before putting it into the reservoir/tank
2. Do the surfacing for every new workpiece to ensure constant starting surface roughness.

3.4 MEASUREMENT METHOD

3.4.1 Tool Flank Wear Measurement and Chip Morphology Analysis using 3D non-contact measurement machine

The measurement machine used is a 3D non-contact measurement machine manufactured by Mitutoyo, modeled 3D QVPAK Quick Vision. The machine (as per standard) has the capability of magnification up to six times but in order to obtain a clear view of the tool wear, the magnification can be used up to two times only. Followings are the visual of the particular measurement machine:

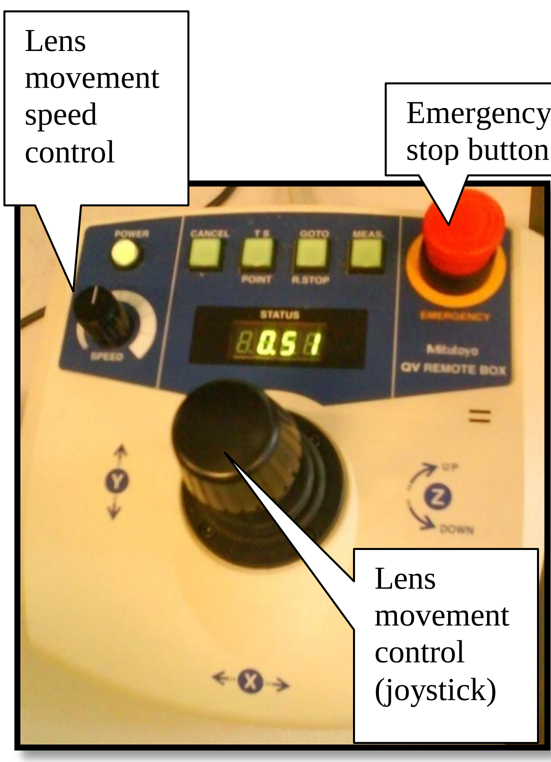


Figure 16: Figure above shows the control panel of the measurement machine

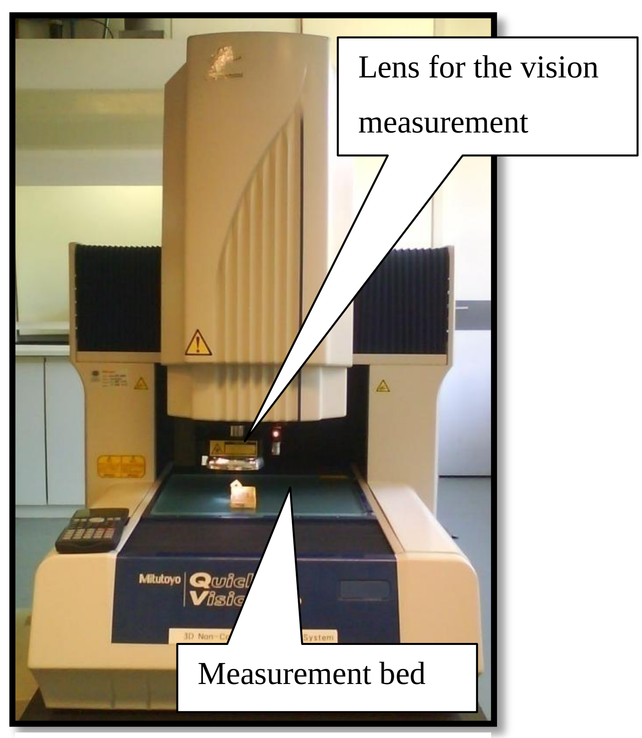


Figure 15: Figure above shows the 3D non-contact measurement machine

Measurement steps are as follows:

1. The tool to be measured is fitted on the measurement bed (fixture using plasticine)
2. The measurement system axes is aligned with the tool's axes (X,Y,Z). This will change the standard axes of the system (or termed as Machine Coordinate System, MCS) to the Predetermined Coordinate System, PCS.

3. The edge where the tool wear is to be measured is determined as singular points. The measurement is based on the distance between these two points.

4. The measurement results are saved as text file (.txt) and the picture captured at the tool wear interface is saved in a Tagged Image File Format (.tif).

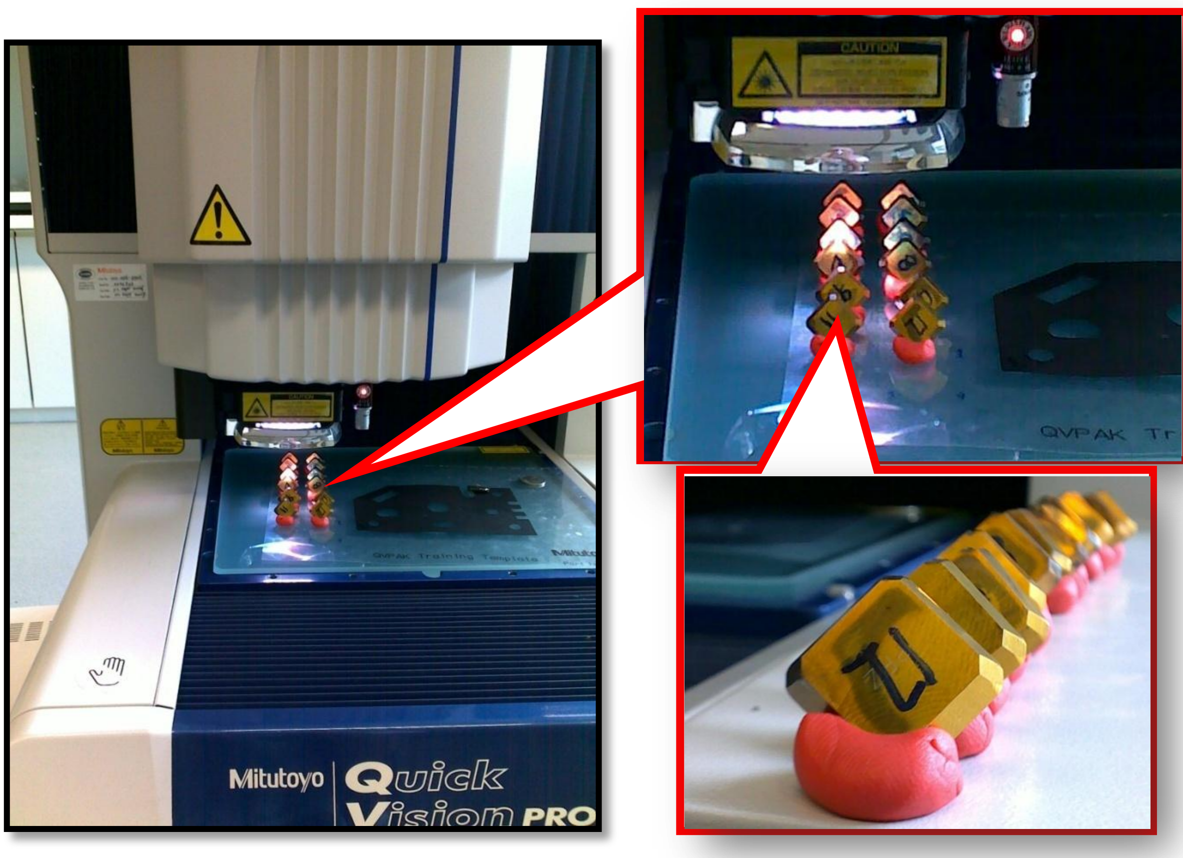


Figure 17: Figure above shows the tool is being placed with the tool face is facing upright in order to measure the tool flank wear

3.4.2 Tool Overall Wear Measurement using high-precision weighing machine, Mettler Toledo AX205

The measurement concept is by measuring the weight loss due to the material of the tool that has worn off from the tool. The measurement of the weight using Mettler Toledo AX205 weighing machine is up to 10micrograms of accuracy.

The weight of the tool is measured before the tool is used. After the tool has been used for certain time such as 5minutes of milling, the tool then weighed using the particular weighing machine to get its new weight.

The data of this measurement is to support the data of tool wear measurement using the 3D non-contact measurement machine.

Figure 18: Figure shows the Mettler Toledo AX205 weighing machine

3.5 ASSUMPTIONS AND LIMITATIONS

1. All variables that are kept constant in the experiments are assumed to have no effect on the results

2. For every run conducted, the surface roughness is assumed to be the same for all of the surfaced workpiece.

3. Workpiece material and tool material composition required is assumed to be as same as per supplied material by supplier.

4. For every test cycle, the CPO used is not being re-used again so that the data obtained is based on the maximum performance of the oil.

5. For every test cycle, the composition and physical properties of the CPO is always the same.

3.6 CRUDE PALM OIL APPLICATION SYSTEM DESIGN

The CPO is applied onto the cutting zone by flooding approach as it is one of the most common and simple method of cutting fluid application.

Four systems are designed to pump in the CPO into the cutting zone and the designs are as follows:

3.6.1 CPO pumping system: Design 1

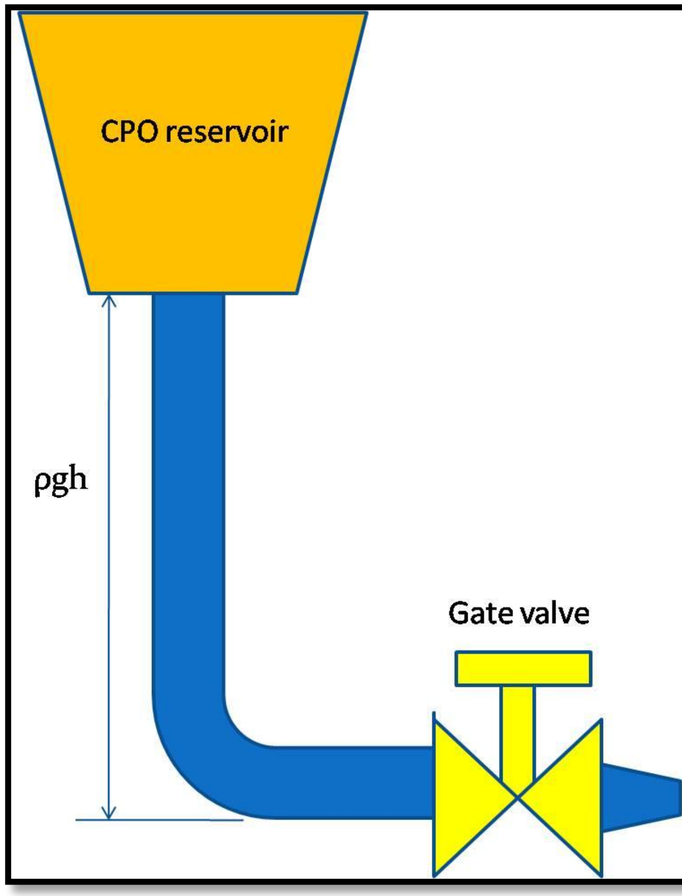


Figure 19: Figure shows the first design of the CPO pumping system.

This is the simplest design that can easily be produced for the experiment. The pressure to pump in the CPO is by gravity of ρgh where ρ is the CPO's density. After tested, the system can achieve up to 4800mL/hr of flow rate. In comparison, as for minimum quantity lubrication (MQL), S. Thamizhmanii, Rosli, S.Hasan [18] claimed that the coolant flow rate is approximately 37.5mL/hr. Due to this result, the particular coolant system can be said as flooding type of application. Therefore, this CPO pumping system is accepted and applied during the experiment.

3.6.2 CPO pumping system: Design 2

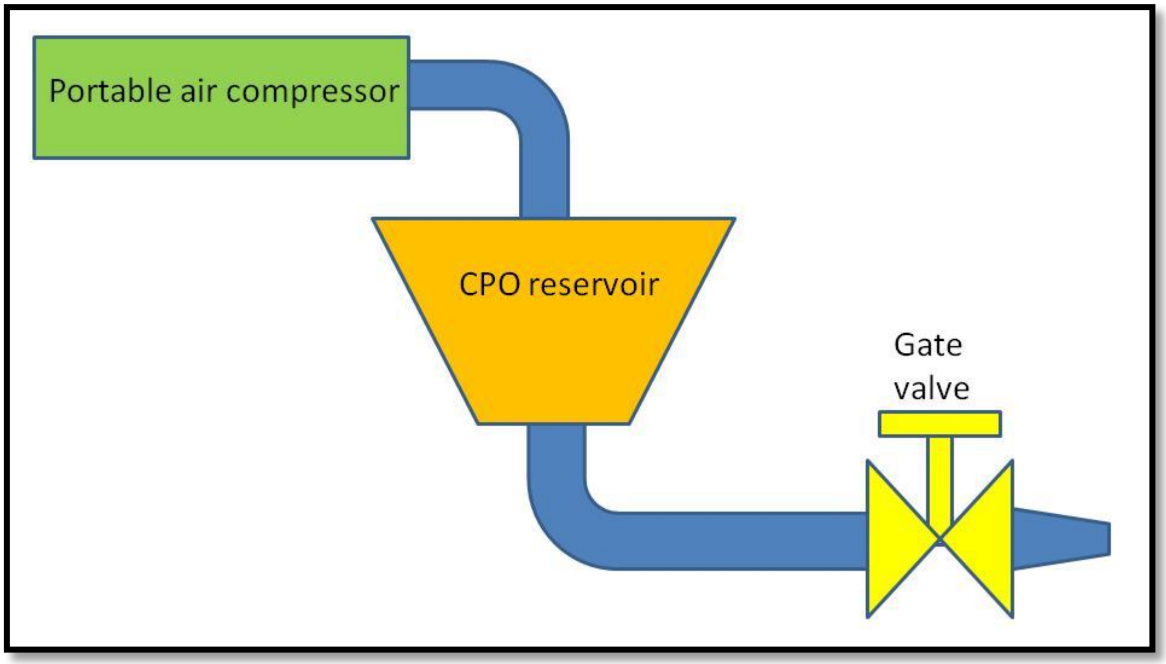


Figure 20: Figure shows the second design for the CPO pumping system

This issue has a drawback where the portable compressor is low in compression capability (range up to only around 200kPa). The design is not used due to its complexity to control the pressure in the system.

3.6.3 CPO pumping system: Design 3

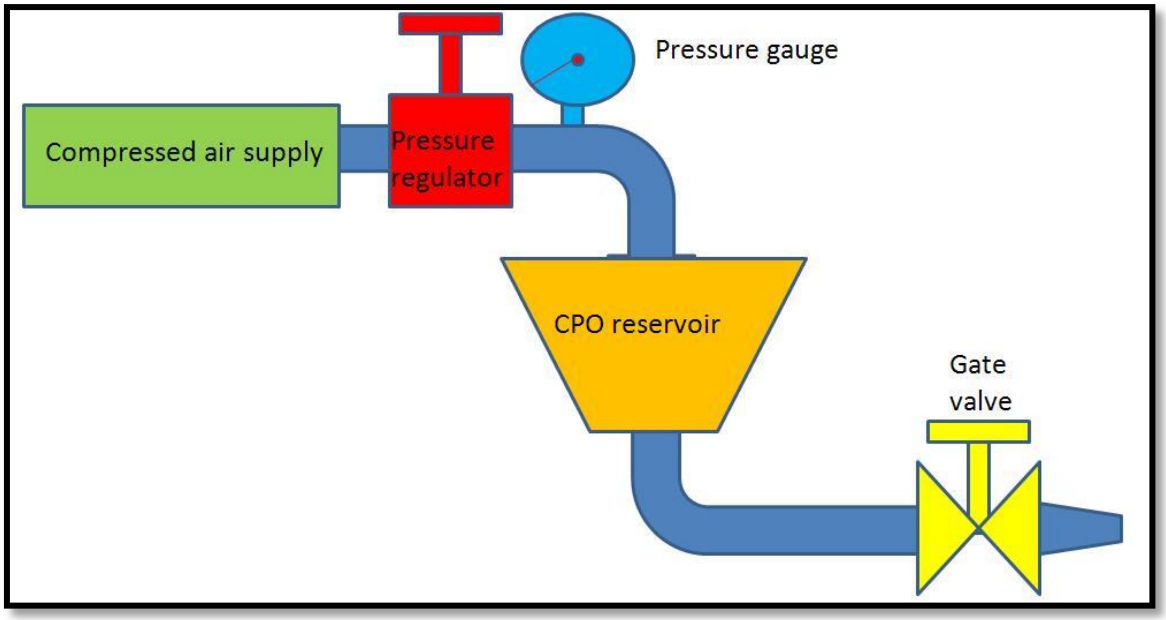


Figure 21: Figure shows the second design for the CPO pumping system

The previous system design is lack of compressive pressure. Therefore, this design is the backup to counter the issue. This design can control the flow rate using the gate valve and the fluid pressure can be control by the pressure regulator to regulate the fluid pressure up to the specified pressure. This design also has the drawback where the CPO reservoir (or tank) has be able to sustain the pressure in order to prevent any failure in the system such as tank explosion. Due to the complexity of the design to be implemented, the design is not used for the experiment.

3.6.4 CPO pumping system: Design 4

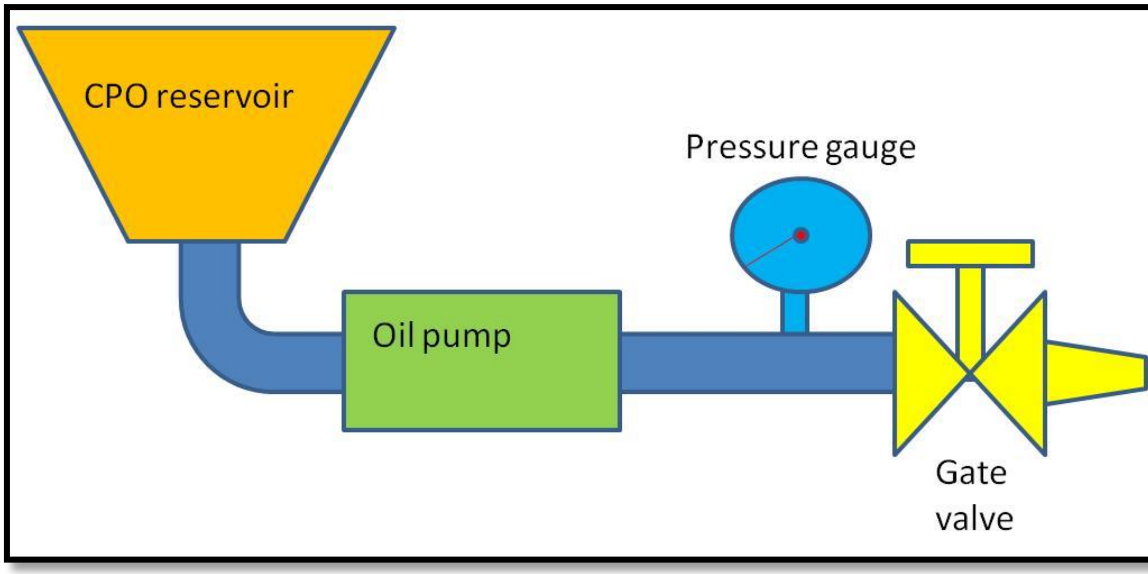


Figure 22: Figure shows the third design of the CPO pumping system

In order to counter the previous problem where the issue of finding the appropriate reservoir/tank, the author came up with this backup design. The oil pump will pump the oil from the reservoir to the gate valve and the gate valve will control the flow. The post-pump pressure is controlled manually by turning it on to charge the pressure up, and turn off the pump when the pressure has reached the desired value. Again, this design is also not being utilized due to its complexity of the design.

3.7 GANTT CHART

Table 10: Table shows the Gantt chart for the project.

No.	Activities	**Week**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Selection of project topic														
2	Preliminary research work														
3	Submission of preliminary work														
4	Project work														
5	Submission of progress report														
6	Seminar														
7	Project work continues														
8	Submission of interim Report Final Draft														
9	Oral presentation														

No.	Activities	**Week**													
		15	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
10	Project work continues														
11	Submission of Progress Report 1				●										
12	Project work continues														
13	Submission of Progress Report 2								●						
14	Seminar (compulsory)								●						
15	Project work continues														
16	Poster exhibition											●			
17	Submission of Final Draft														●
18	Oral presentation														
19	Submission of Dissertation (hard bound)														
			Process												
		●	**Milestones**												

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 TOOL WEAR

4.1.1 Tool Flank Wear

→Tool flank wear behavior with respect to machining time

Table 11: Table shows the results of mean flank wear for the first speed with intervals of 5 minutes.

Condition	Mean flank wear in particular machining time (mm)				
	5minutes	10minutes	15minutes	20minutes	25minutes
SCF*	0.000	0.139	0.282	5.003	5.003
CPO	0.028	0.134	0.202	0.265	0.329

**SCF = Standard cutting fluid (Solkut)*

The above machining takes place with following parameters:

Cutting speed – 120m/min

Spindle speed – 630rpm

Feed rate – 200mm/min

From the data, it is shown that milling using CPO as the cutting fluid initially gives a bit higher tool wear as compared to standard cutting fluid. As the machining time continues, the standard cutting fluid gives a sudden catastrophic failure to one of the insert, giving the average tool wear climbing up in a high rate during 20 minutes of machining. From this particular cutting parameter, the results indicated that milling using CPO as the cutting fluid gives the best tool life compared to other cutting conditions.

→Tool flank wear behavior with respect to cutting speed

Table 12: Table shows the mean flank wear for three cutting conditions with three different cutting speeds.

Speed, V (m/min)	Condition	Mean flank wear, V_B (mm)
120	SCF	1.504
170	SCF	2.600
220	SCF	1.301
120	CPO	0.553
170	CPO	2.566
220	CPO	1.316

The above data took place with following cutting parameters:

- Speed 1:
  - Cutting speed, V=120m/min
  - Spindle speed, N=630RPM
  - Feed rate, *v*=200mm/min
- Speed 2:
  - Cutting speed, V=170m/min
  - Spindle speed, N=800RPM
  - Feed rate, *v*=315mm/min
- Speed 3:
  - Cutting speed, V=220m/min
  - Spindle speed, N=1250RPM
  - Feed rate, *v*=400mm/min

From the above data, it is shown that during high speed milling, the tool wear of milling using CPO and standard cutting fluid are almost similar. As for the dry machining, as per predicted, will have much higher tool wear at high speed milling. This is a good indication of the feasibility of using CPO as the cutting fluid for machining.

However, the phenomenon that happens during the second speed (170m/min) is quite surprising because the tool wear of milling without using any cutting fluid is much better as compared to the other tool wear that utilizes cutting fluid during milling. With reference to literature by S. Thamizhmanii, Rosli, S.Hasan [18], this phenomenon is explained by the phenomenon of Minimum Quantity Lubrication (MQL) where the machining takes place at a very minimum cutting fluid application. It is also stated in the literature that the conventional flooding application of cutting fluid does not always gives better tool life but instead, reduces the tool life or in this case, causes the tool wear even more compared to the condition that does not utilize any cutting fluid.

This data is supported by following results on the overall tool wear and also the visual examination of the tool flank face.

4.1.2 Visual results from 3D non-contact measurement machine

For cutting speed 1 (120m/min), followings are the pictures taken under 3D Non-contact Measuring Machine:

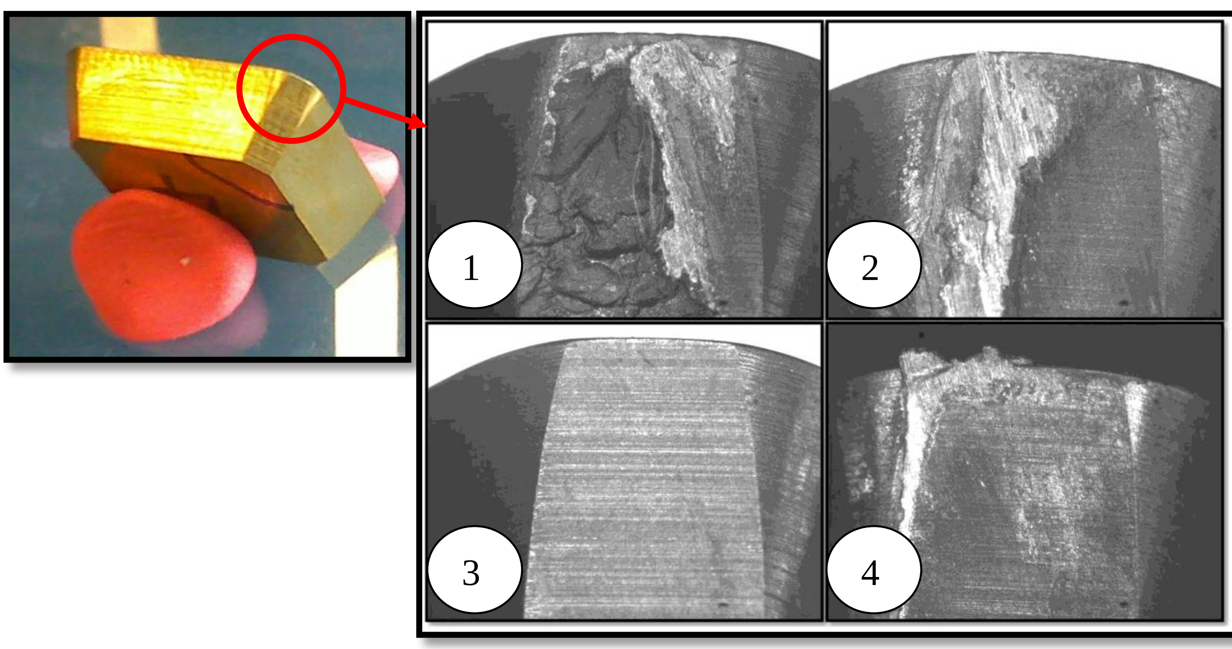


Figure 23: Flank face of the inserts used for the dry milling (Magnification 2X)

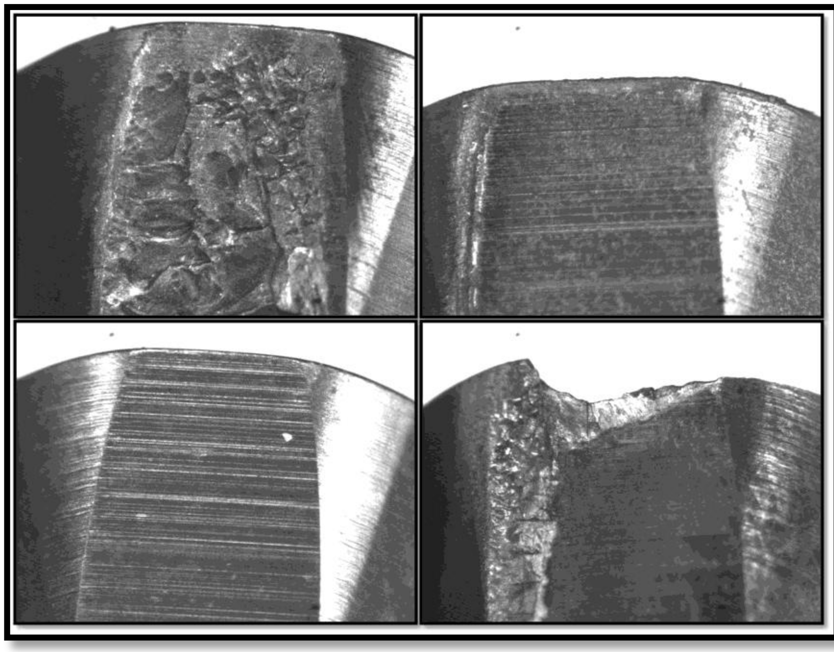


Figure 24: Figure shows flank face of the inserts used for the milling using standard cutting fluid (Magnification 2X)

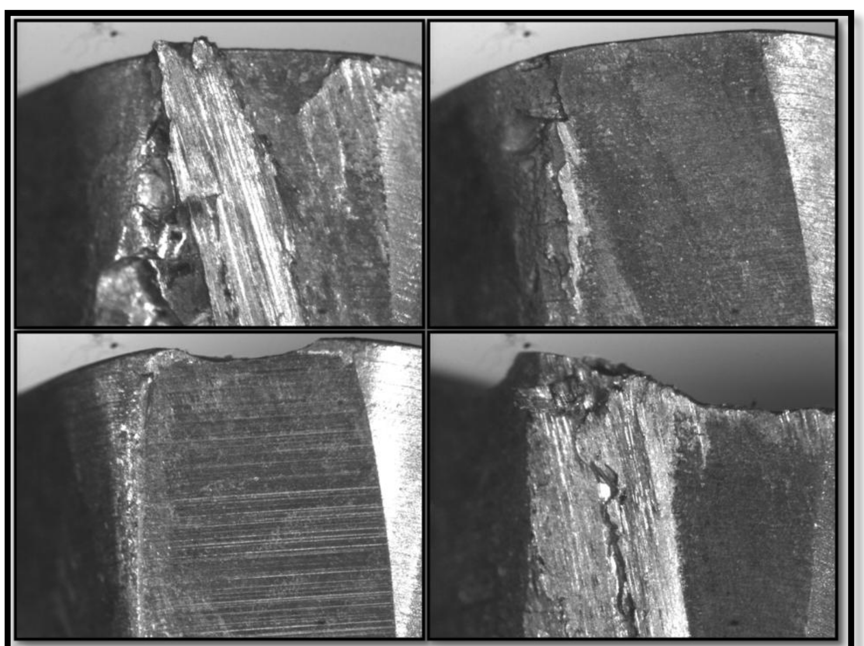


Figure 25: Figure shows flank face of the inserts used for the milling using CPO as cutting fluid (Magnification 2X)

Above three figures (Figure 23 to 25) are arranged according to insert positions. In order to compare these three cutting conditions, the inserts can be compared with the same insert position. For instance, Insert 1 in Figure 23 can be directly compared with Insert 1 in Figure 24 and 25.

For the insert position 1 for dry machining (Figure 23), the insert flank face has catastrophically damaged. Even though insert 1 that used for milling using standard cutting fluid are also catastrophically damaged, but physically in is shown that the depth of the wear are lesser when the tool are used with standard cutting fluid. Different cases happen when the insert is used with CPO as the cutting fluid where not all of the flank face of the insert is catastrophically. This phenomenon indicates that CPO somehow reduces tool wear even better compared to standard cutting fluid. On the other hand, if the tool wear is taken by mean, the tool wear between standard cutting fluid and CPO are relatively similar to each other as indicated data tabulated in the previous part.

Insert position 4 in Figure 24 and 25 has a chipped-off cutting edge. This phenomenon is commonly occurs in milling process but rarely exist during lathe or drilling. This phenomenon is actually due to the fact that milling is and interrupted cutting operation where the tool cutting edge enters and exits workpiece several times per second. Due to this enter and exit actions, the tool cutting edge are introduced with much impact thus, making the tool cutting edge fatigued and chipped off. The other pictorial data for other speeds are placed in Appendix A-4 for further reference.

4.1.3 Overall tool wear

The overall tool wear is tool wear measurement where the weight loss of the inserts due to the machining is measured. This weight loss resembles the inserts overall tool wear because the measured weight loss consists of every single wear that exist on the insert.

Followings are the data of the measured overall too wear:

Table 13: Table shows the data for the overall tool wear measurement by insert weight loss measurement

Condition	Cumulative mean insert weight loss after particular time machining (mm)					
	0min	5min	10min	15min	20min	25min
SCF*	0.0000	0.0002	0.0002	0.0004	0.0017	0.0059
CPO	0.0000	0.0007	0.0010	0.0016	0.0024	0.0062

SCF=Standard cutting fluid*

Referring to data above, the data is consistent with the tool flank wear measurement. This consistency indicates that the tool flank wear measurement using 3D Non-contact Measurement Machine is relevant to the particular condition.

The plot also indicates that CPO's performance as cutting fluid is similar to performance of standard cutting fluid.

Table 14: Table shows the data for the overall tool wear measurement for various speed and various cutting conditions.

Speed (m/min)	Condition	Weight loss (g)
120	SCF	0.0059
170	SCF	0.0182
220	SCF	0.0119
120	CPO	0.0029
170	CPO	0.0208
220	CPO	0.0068

The data in Table 13 which is the overall tool wear measurement, is again has the similar characteristic with data in Table 12 on the tool flank wear. This particular phenomenon proven the fact that flank wear is the major wear that occurs in the tool (insert) because the overall tool wear behavior is influenced by the tool flank wear.

4.2 CHIP FORMATION

Followings are the pictures of chips that are captured under 3D Non-contact Measurement Machine for milling with cutting speed of 120m/min:

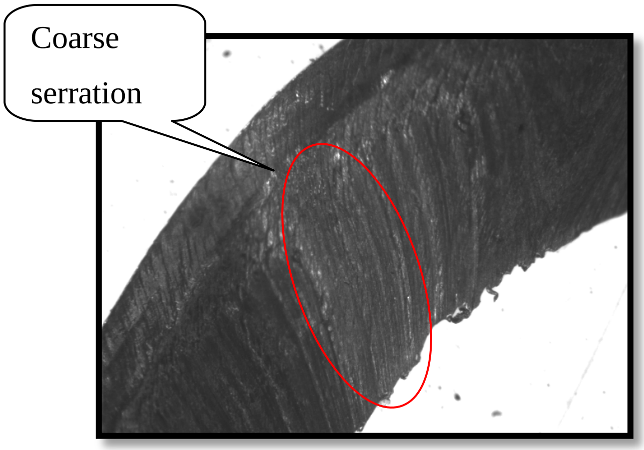


Figure 27: Dry milling (Magnification 2X)

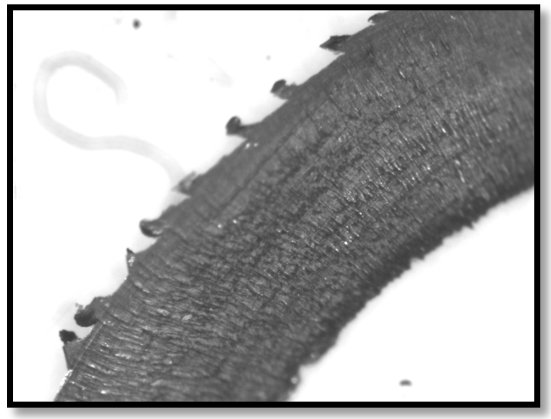


Figure 26: Milling using SCF (Magnification 2X)

Figure 28: Milling using CPO (Magnification 2X)

From above Figures (26 to 28), it is shown that all of the chips produced by milling either utilizing or not utilizing cutting fluid, the chip produced are mainly serrated type chip. And of course, due to the interrupted cutting mechanism of milling process, all of the chips produced are discontinuous chips.

On the other hand, significant difference in serration behavior can be seen when dry milling is practiced (marked in Figure 27). The serration seems to be coarser as compared to other chips produced when milling with cutting fluids. This serration behavior is believed to be due to the growth of cracks from the outer surface of the chip [19][20],or adiabatic shear band formation [21][22], which is caused by localized shear formation because of the thermal softening at the cutting edge. In other words, the coarser behavior shows the higher heat took place at the cutting zone during the milling operation.

From above Figure also (Figure 28), the serration of the chip that milled using CPO as cutting fluid can be seen much smoother compared to the one in Figure 30 which was milled using standard cutting fluid. This indicates a great lubrication has been introduced by CPO at the cutting zone and thus, reduces very much of heat generated due to the material removal process. The same phenomenon also can be seen when milling at higher cutting speed (170m/min).

For milling at cutting speed of 170m/min:

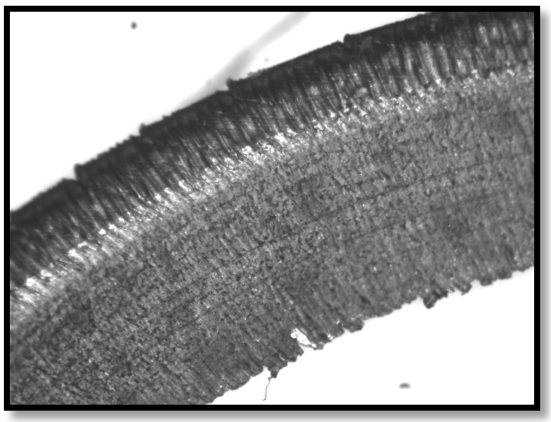


Figure 30: Dry milling (Magnification 2X)

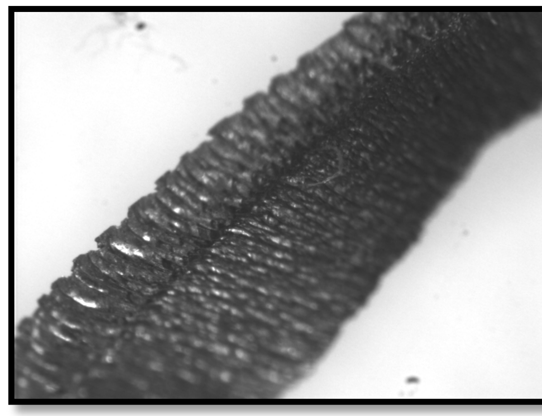


Figure 29: Milling using SCF (Magnification 2X)

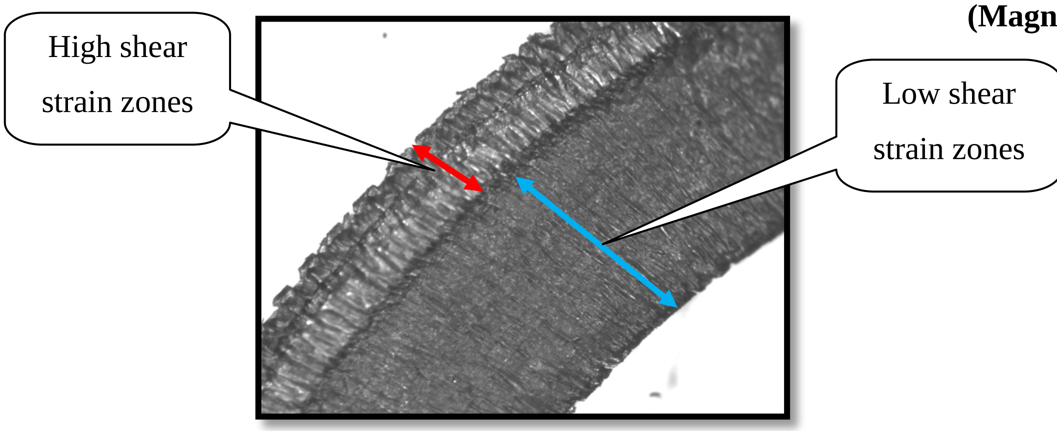


Figure 31: Milling using CPO (Magnification 2X)

According to Serope Kalpakjian, Steven Schmid [16], these serrated or segmented chips are semi-continuous chips (not continuous but not really discontinuous chips). They come with large zones of low shear strain and small zones of high shear strain (Figure 31). This phenomenon is exhibited by metal with low thermal conductivity and strength that decreases sharply with temperature.

From Mustafa Bakkal, Albert J. Shih, Ronald O. Scattergood [23] also, stated that AISI 304 austenitic stainless steel has shear localization due to relatively low thermal conductivity.

For milling at cutting speed of 220m/min:

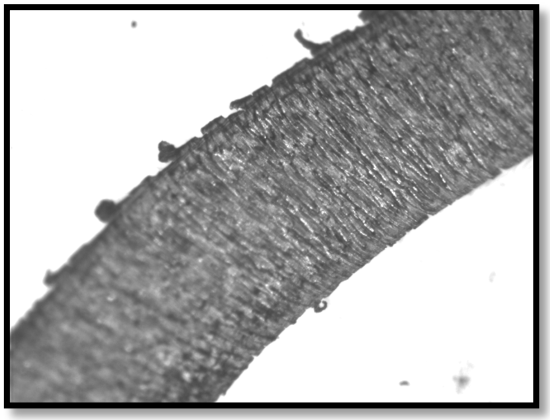


Figure 33: Dry milling (Magnification 2X)

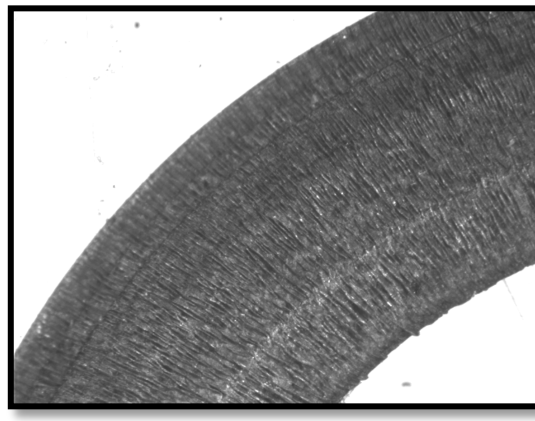


Figure 32: Milling using SCF (Magnification 2X)

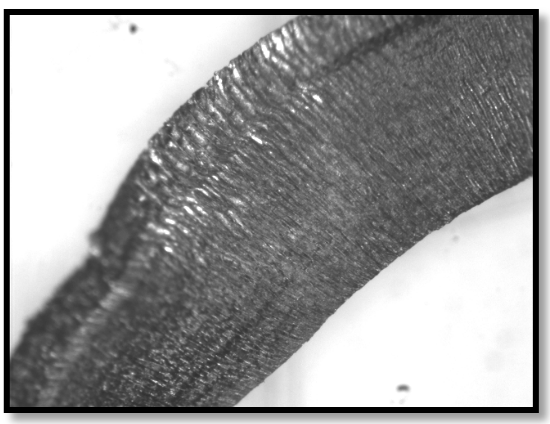


Figure 34; Milling using CPO (Magnification 2X)

A slight difference can be noted on the above figures (32 to 34) when the milling process took place at high speed (220m/min). It can be seen that

1. Chip in Figure 32 has a finer serration compared to other chips and
2. Chip in Figure 33 has a smaller width compared to other chips.

As for the first phenomenon, the high speed milling produces much heat. Due to the characteristic of good cooling behavior of standard cutting fluid (soluble mineral oil, have the existence of water derivatives), the cutting fluid successfully absorbed very much better heat compared to CPO. The oil characteristic of CPO (good lubrication, moderate cooling) could not sustain the optimum cooling and lubrication at high speed milling condition.

From this phenomenon, it can be concluded that at low speed, lubrication is crucial compared to cooling, whereas cooling is much crucial compared to lubrication when the milling is done at high speed.

4.3 OTHERS

The measurements of the tool wear using the 3D non-contact measurement machine involve quite a number of errors and limitations. Due to this, in order to reduce the error, other tool wear measurements (overall tool wear measurement) are also implemented in order to ensure the results' accuracy.

The other options of tool wear measurements are as follows:

- Tool weight loss due to wear
- Pictorial comparison

By having two measurement results, the accuracy of the reading at least will indicate the consistency of the measurements with each other. Due to that, the accuracy of the result can be assured.

There are very much improvement also has to be done after this project is completed. One of the most popular issue of using CPO as the cutting fluid is on its pH value which is acidic in nature. This is very crucial to be countered in order to reduce the hinder of its market to grow much further. The pH can be modified by using certain additives as the pH modifiers to stabilize the pH value to a more neutral or a bit alkali.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Cutting fluids play a significant role in machining operations and has a great impact on the manufacturing productivity especially in mass production.

From the experiments, for milling, it is proven that flank wear is the dominant tool wear mode compared to other tool wears such as BUE.

It is also been proven that CPO has a high potential to replace standard cutting fluid which is non-biodegradable soluble mineral based cutting fluid. Therefore, a further investigation should be continued in order to ensure this environmental friendly idea is developed for a better future of manufacturing sector.

5.2 RECOMMENDATIONS

There are few recommendations obtained from this experiment for the future of CPO developments as cutting fluids. The recommendations are as follows:

1. **Utilization of Minimum Quantity Lubrications (MQL)**

   In this experiment, it was indicated that flooding application technique of cutting fluid not always the best way to reduce tool wear. Sometimes, the flooding also increases the tool wear in certain conditions. Therefore, utilization of MQL technique might help in improving CPO performance much further.

2. **Application of additives to improve CPO performance as cutting fluid**

CPO has certain limitations such as its acidic nature has induced the corrosion in metal which has low or no corrosion resistance. Due to this phenomenon, it will be much better if the CPO acidity can be reduced so that a wide range of materials can be used for machining using CPO as cutting fluid.

On top of that, CPO has also another limitations which are the solidification temperature are relatively high where if the CPO are left unattended in the lab with air-conditioned environment, or even in room temperature, the CPO will solidify in a short period of time. Therefore, additives to reduce its solidification temperature will help it to perform better during machining as the phase can be maintained throughout the machining process.

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APPENDIX

A-1 Detailed Spindle Speed Calculations

Spindle speed, N=

$$Spindle\ speed, N = \frac{V}{\pi D_0}$$

Where,

V = Cutting speed

D_0 = Cutter diameter

Therefore, for cutting speed 1=120m/min

$$Spindle\ speed, N = \frac{120m/min}{\pi 0.06m}$$

$$Spindle\ speed, N = 636.62rev/min$$

For cutting speed 2=170m/min

$$Spindle\ speed, N = \frac{170m/min}{\pi 0.06m}$$

$$Spindle\ speed, N = 901.88rev/min$$

For cutting speed 3=220m/min

$$Spindle\ speed, N = \frac{220m/min}{\pi 0.06m}$$

$$Spindle\ speed, N = 1167.14rev/min$$

In the Excel FU281 Universal Milling Machine, the preset input of spindle speeds are as follows:

50RPM	400RPM	200RPM	1600RPM	100RPM	800RPM
40RPM	315RPM	160RPM	1250RPM	630RPM	630RPM
63RPM	500RPM	250RPM	20000RPM	125RPM	1000RPM

Cutting speed, V (m/min)	**Calculated spindle speed, N (RPM)**	**Available preset spindle speed (RPM)**
120	636.62	630
170	901.88	800
220	1167.14	1250

A-2 Detailed Feed Rate Calculations

Feed = 0.08mm/tooth

$$Feed\ rate, v = fNn$$

Where

f = feed as per recommended

N = Spindle speed as per calculated

n = number of tooth

Therefore, feed rate for speed 1 (120m/min):

$$Feed\ rate, v = 0.08mm/tooth \times 630RPM \times 4tooth$$

$$Feed\ rate, v = 201.6mm/min$$

Feed rate for speed 2 (170m/min):

$$Feed\ rate, v = 0.08mm/tooth \times 800RPM \times 4tooth$$

$$Feed\ rate, v = 256.0mm/min$$

Feed rate for speed 3 (220m/min):

$$Feed\ rate, v = 0.08mm/tooth \times 1250RPM \times 4tooth$$

$$Feed\ rate, v = 400.0mm/min$$

200	315	500	400	630	125	100	160
25	40	63	50	80	16	12.5	20

Cutting speed, V (m/min)	**Calculated feed rate, *v* (mm/min)**	**Available preset feed rate (mm/min)**
120	201.6	200
170	256.0	315
220	400.0	400

A-3 Detailed MRR Calculations

As for the material removal rate (MRR), followings are the particular calculations:

$$MRR = wdv$$

Where

W = width of the workpiece

d = depth of cut

v = feed rate

Therefore, for first feed rate (200mm/min), the MRR is:

$$MRR = 50mm \times 0.1mm \times 200mm/min$$

$$MRR = 1000mm^3/min$$

Therefore, for second feed rate (315mm/min), the MRR is:

$$MRR = 50mm \times 0.1mm \times 315mm/min$$

$$MRR = 1575mm^3/min$$

Therefore, for third feed rate (400mm/min), the MRR is:

$$MRR = 50mm \times 0.1mm \times 400mm/min$$

$$MRR = 2000mm^3/min$$

A-4 Pictorial data for the tool wear

Cutting speed 2 (170m/min):

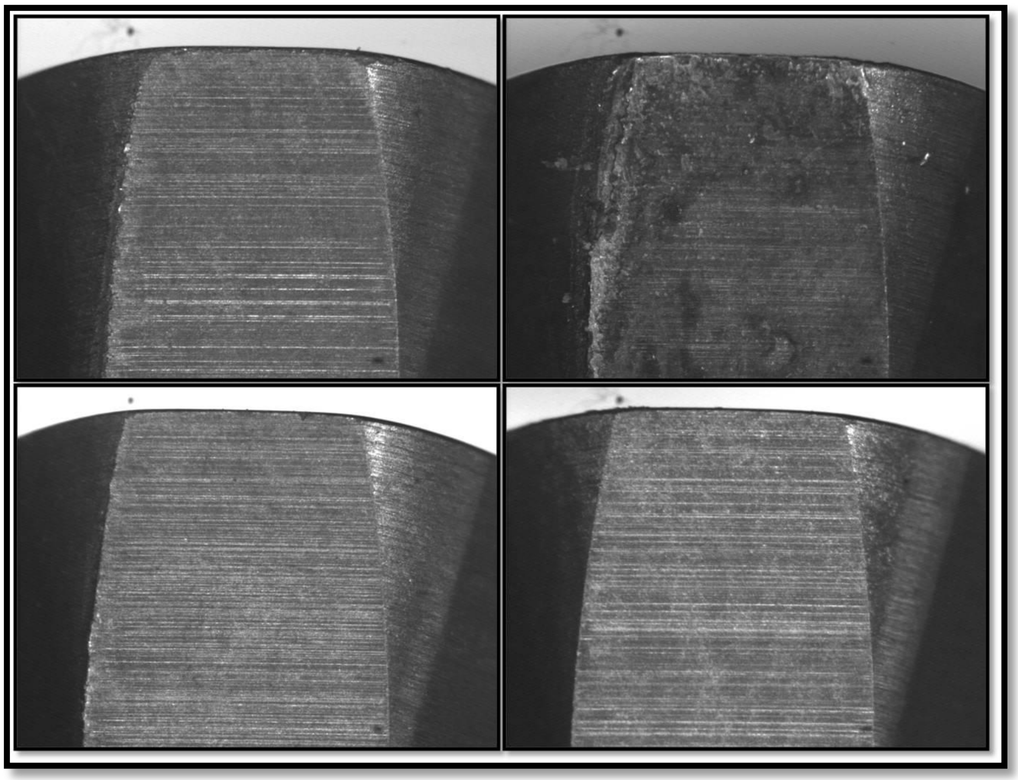


Figure 35: Condition =Dry (Magnification2X)

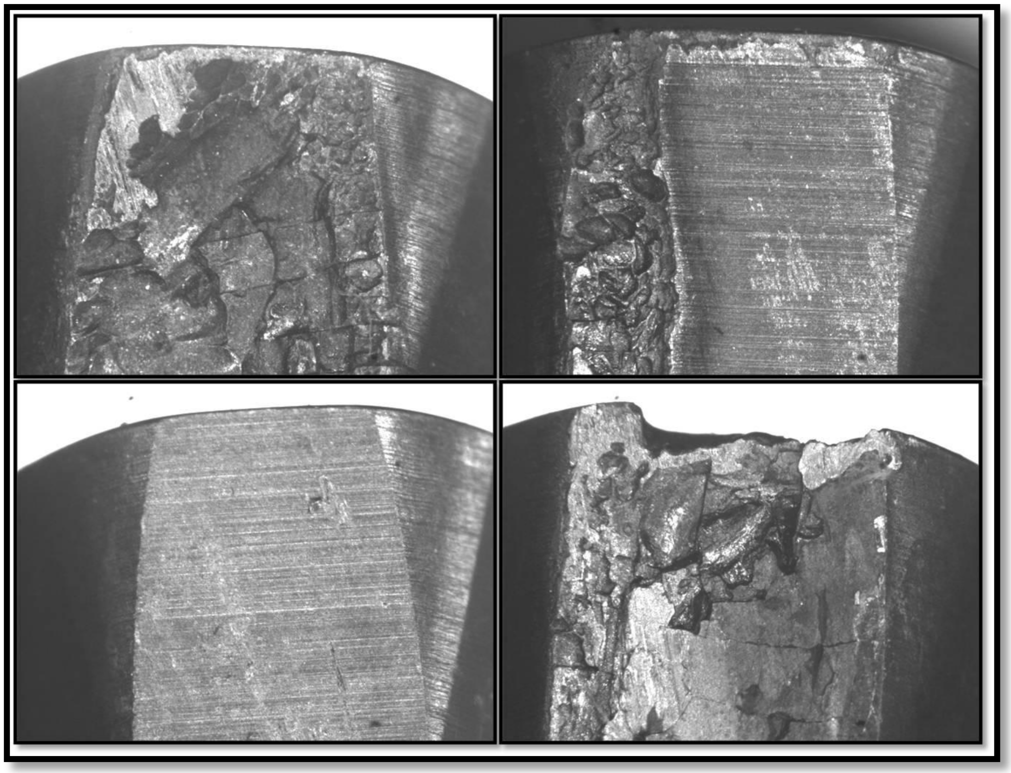


Figure 36: Condition = using standard cutting fluid (Magnification2X)

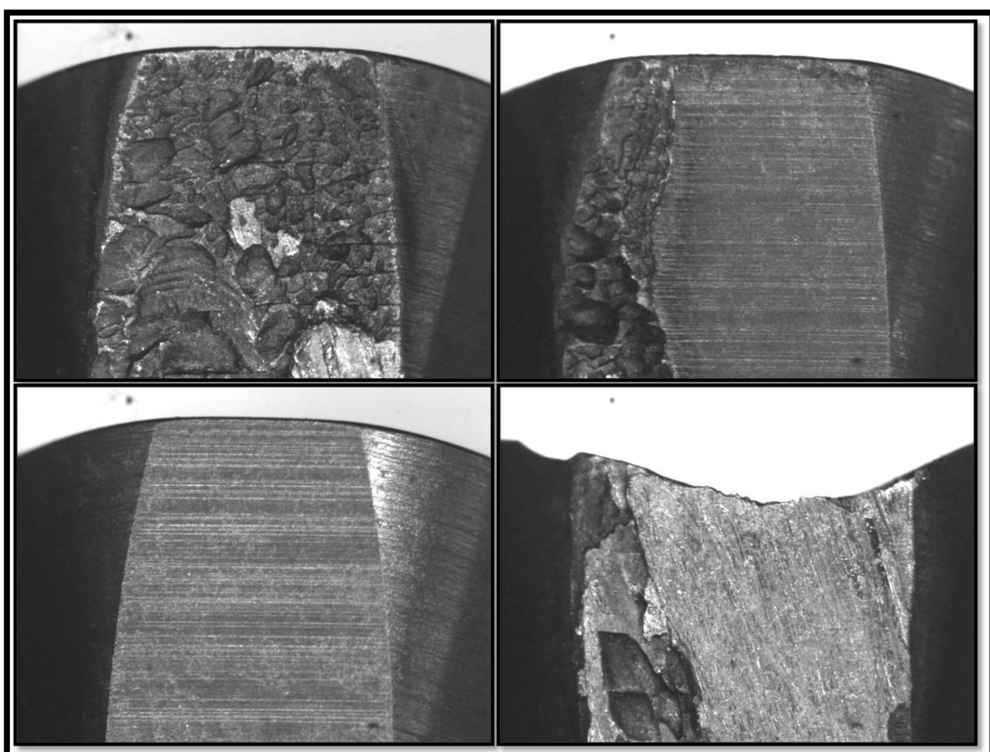


Figure 37: Condition=using CPO as cutting fluid (Magnification2X)

Cutting speed 3 (220m/min):

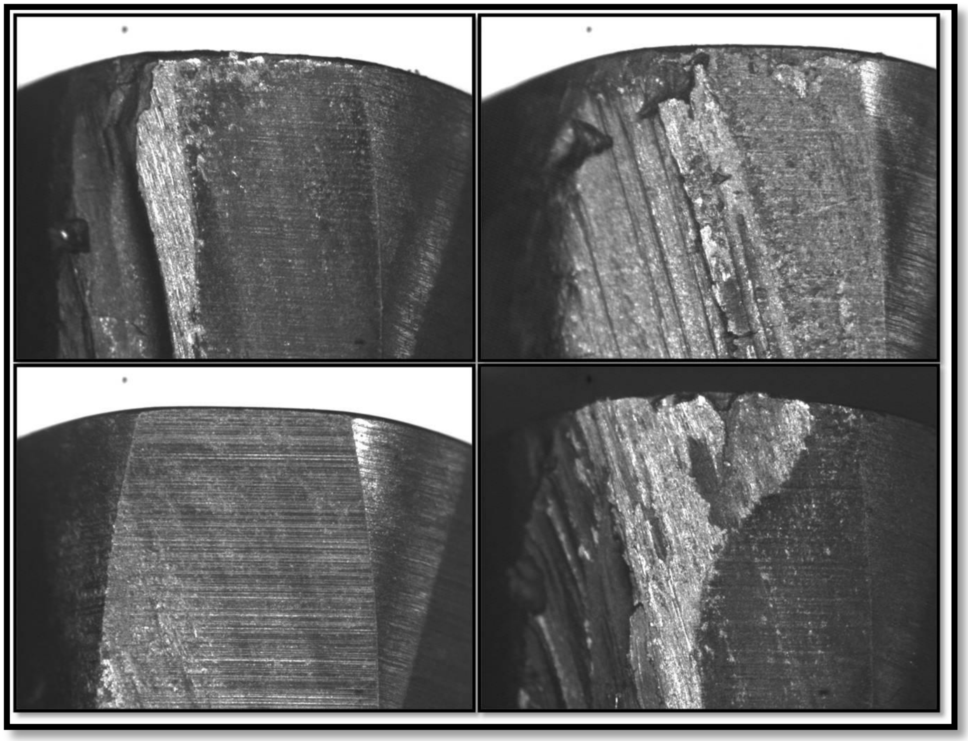


Figure 38: Condition=Dry (Magnification2X)

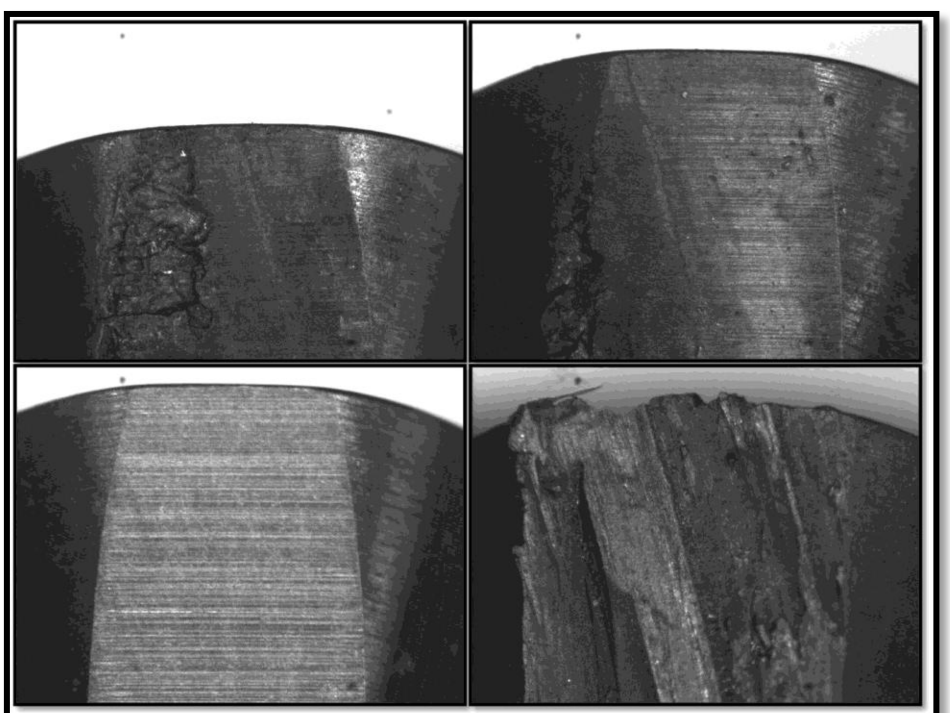


Figure 39: Condition = using standard cutting fluid (Magnification2X)

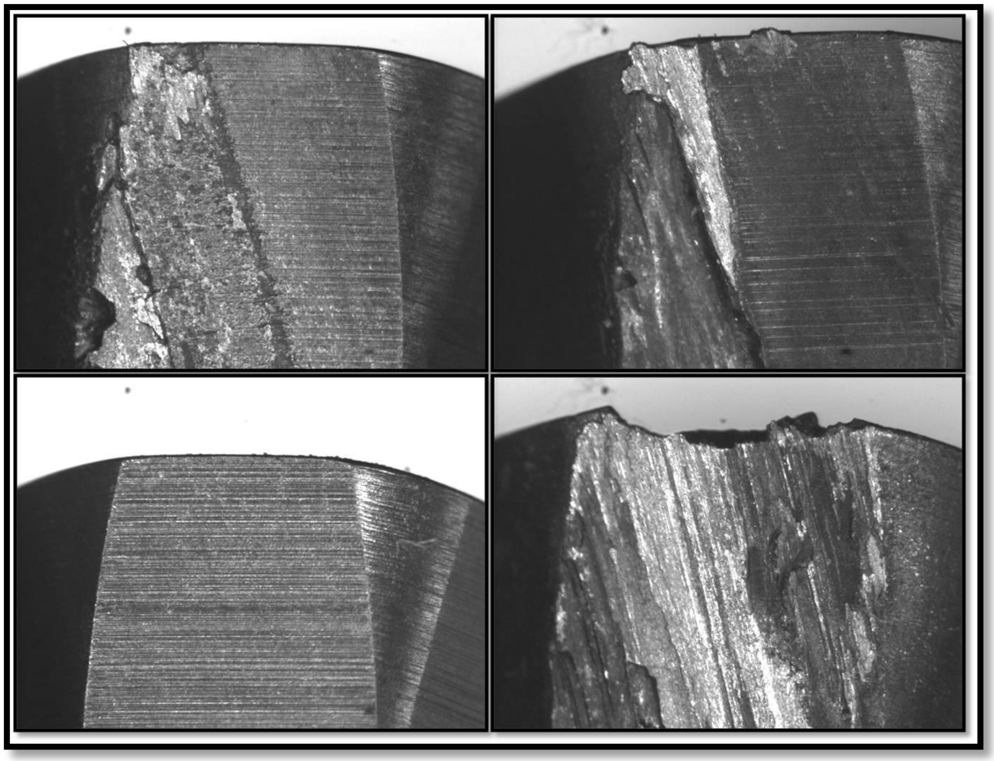
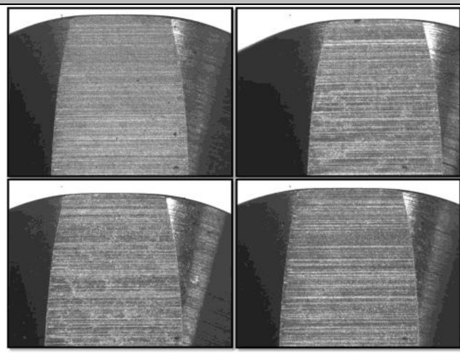
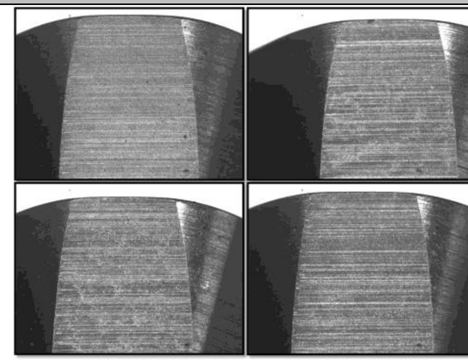
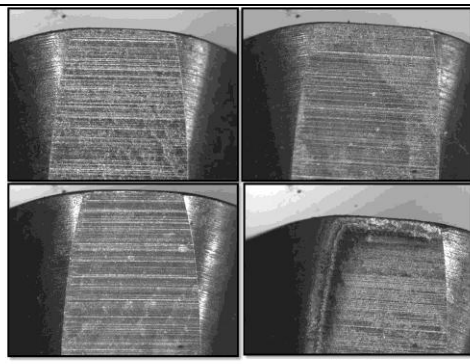
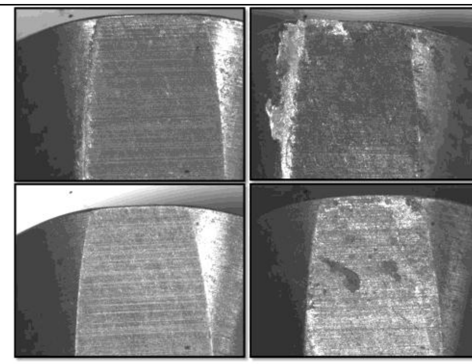
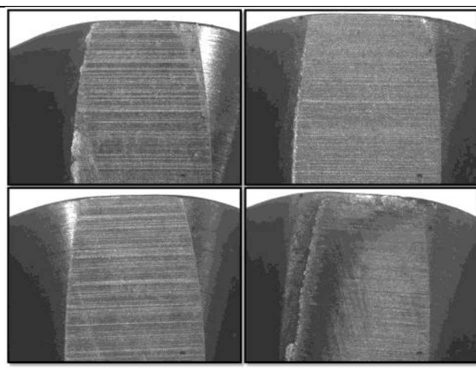
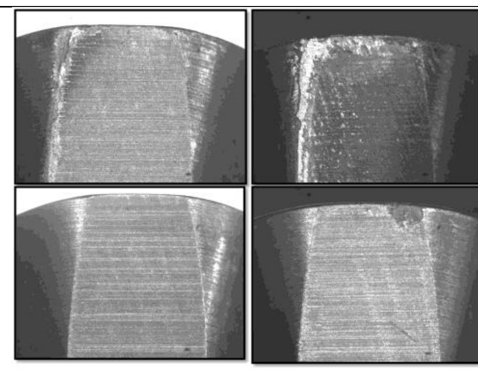
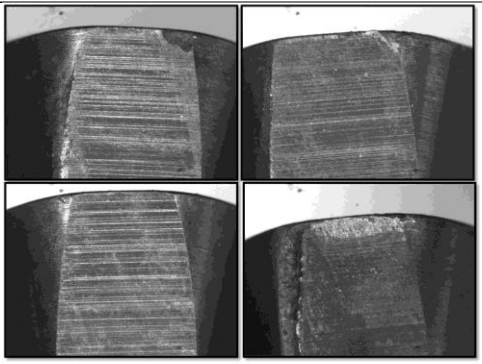
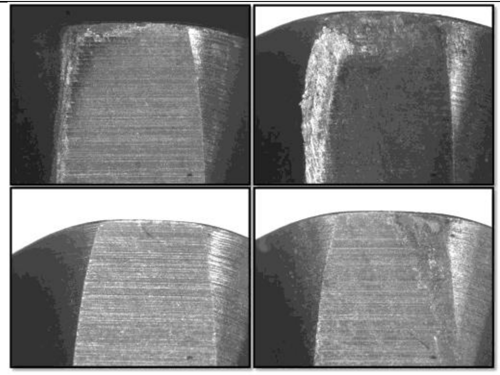
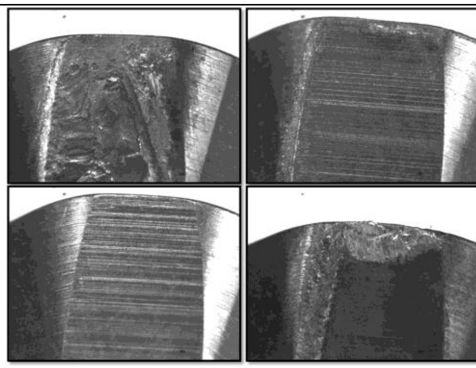
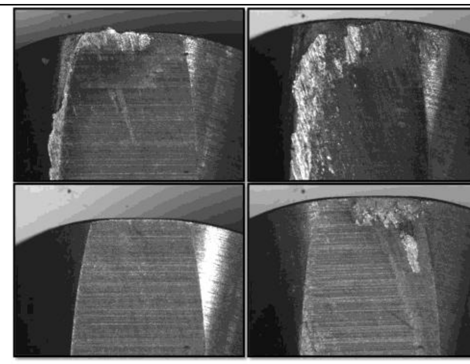
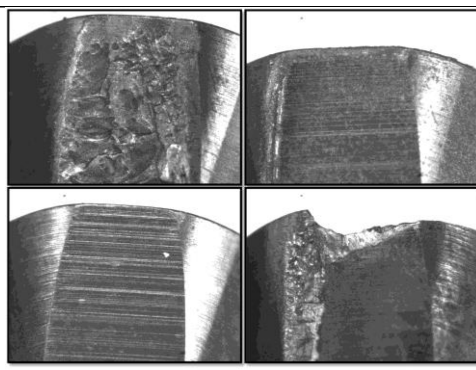


Figure 40: Condition = Using CPO as cutting fluid (Magnification 2X)

Followings are table to compare between two tool wear between two cutting conditions: Standard cutting fluid versus CPO in 5-minute intervals:

Inserts using standard cutting fluid	**Machining time (min)**	**Inserts using CPO as cutting fluid**
	0	
	5	
	10	

	15	
	20	
	25