KEMENTERIAN PENDIDIKAN TINGGI

JOJAPS

eISSN 2504-8457

POLITEKNIK MALAYSIA PORT DICKSON

Journal Online Jaringan COT POLIPD (JOJAPS)

Lathe Machine and Dry Turning Method in order to Predict Tool Performance and Improve Surface Roughness

Mmaniyarasi Munusamy, Tamil Moli Loganathan,
Mohd Khazaren Kusaini

Mechanical Engineering Department, Polytechnic of Banting Selangor,
Persiaran Ilmu, Jalan Sultan Abdul Samad, 42700 Banting
m.maniyarasi.poli@polibanting.edu.my, tamilmoli@polibanting.edu.my, khazaren@gmsil.com

Abstract

In this research parameters such as tool performance, surface roughness in turning process under, dry and near-dry conditions are considered using conventional lathe machine. Minimum Quantity Lubrication (MQL) and dry turning method are carried out and compared. Carbide coated cutting tool is used in conventional dry turning lathe machine with minimal fluid or dry application method by varying depth of cut, feed rate and speed. Consequently, the wear of the tool and the surface roughness of the work piece with different conditions are considered. The finding proves that under certain cutting conditions the predicted tool life under near-dry lubrication are increased compared to dry turning. The tool life with appropriate material properties and cutting conditions can be calculated by means of the parameters in near-dry turning method. Carbide tool performance with minimum amount of lubrication is analysed primarily in this research.

Keywords: Dry Turning, Minimum Quantity Lubrication (MQL), Tool Wear, Surface Roughness

1.0 Introduction

In all machining processes, tool wear is a natural phenomenon and it leads to tool failure. The growing demands for high productivity of machining need use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature, which not only reduces tool life but also impairs the product quality. Metal cutting fluids changes the performance of machining operations because of their lubrication, cooling, and chip flushing functions but the use of cutting fluid has become more problematic in terms of both employee health and environmental pollution. The use of cutting fluid generally causes economy of tools and it becomes easier to keep tight tolerances and to maintain workpiece surface properties without damages. Due to these problems, some alternatives has been sought to minimize or even avoid the use of cutting fluid in machining operations. Some of these alternatives are dry machining and machining with minimum quantity lubrication (MQL).

A lathe is a tool that rotates the workpiece on its axis to perform various operations such as cutting, sanding, knurling, drilling, or deformation, facing, turning, with tools that are applied to the workpiece to create an object with symmetry about an rotation. Lathes are used in woodturning, metalworking, metal spinning, thermal spraying, parts reclamation, and glass-working. Lathes can be used to shape pottery, the best-known design being the potter's wheel. Most suitably equipped metalworking lathes can also be used to produce most solids of revolution, plane surfaces and screw threads or helices. Ornamental lathes can produce three-dimensional solids of incredible complexity. The workpiece is usually held in place by either one or two centres, at least one of which can typically be moved horizontally to accommodate varying workpiece lengths. Other work-holding methods include clamping the work about the axis of rotation using a chuck or collet, or to a faceplate, using clamps or dogs. Examples of objects that can be produced on a lathe include candlestick holders, gun barrels, cue sticks, table legs, bowls, baseball bats, musical instruments (especially woodwind instruments), crankshafts, and camshafts.

Turning

Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helix toolpath by moving more or less linearly while the workpiece rotates. The tool's axes of movement may be literally a straight line, or they may be along some set of curves or angles, but they are essentially linear (in the non-mathematical sense). Usually the term "turning" is reserved for the generation of external surfaces by this cutting action, whereas this same essential cutting action when applied to internal surfaces (that is, holes, of one kind or another) is called "boring". Thus the phrase "turning and boring" categorizes the larger family of (essentially similar) processes. The cutting of faces on the workpiece (that is, surfaces perpendicular to its rotating axis), whether with a turning or boring tool, is called "facing", and may be lumped into either category as a subset.

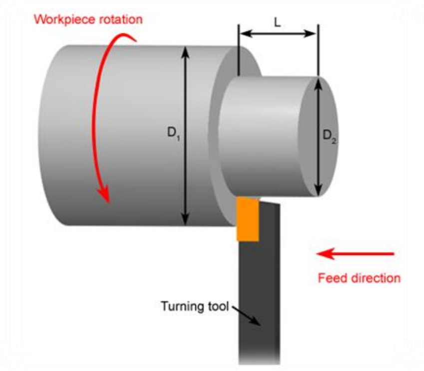


Figure 1: Turning Process

2.0 Work Piece Material

Steel

Metals and alloys have many useful engineering properties and so have extensive application in engineering designs. Iron and its alloys (principally steel) account for about 90 percent of the world's production of metals mainly because of their combination of good strength, toughness and ductility at a relatively low cost. Each metal has special properties for engineering designs and is used after a comparative cost analysis with other metals and materials. (Smith, 2006) Steel is an alloy of iron that contains carbon ranging by weight between 0.02% and 2.11%. It often includes other alloying ingredients as well: manganese, chromium, nickel and molybdenum; but it is the carbon content that turns iron into steel. There are hundreds of compositions of steel available commercially. Generally, they can be grouped into four categories which are plain carbon steels, low alloy steels, stainless steels and tool steels. (Groover, 2007) Only the first category will be discussed here. Plain carbon steels are containing manganese as an alloying enhances strength and hardness that ranges between 0.30 and 0.95 percent. Plain carbon steels have three classes: low carbon steels (less than 0.20% carbon content), medium carbon steels (0.20% to 0.50% carbon content) and high carbon steel (greater than 0.50% carbon content). As the carbon content of the plain carbon steels is increased, the steels become stronger but less ductile. Plain carbon steels have been used in industry for strengthen parts and often used in forgings, gears, and other parts for automotive and structural applications. (Smith, 2006).

Medium Carbon Steel

Medium Carbon Steel Groove, 2007 has stated that carbon steel with carbon content ranging 0.20% to 0.50% is termed as medium carbon steel. They are specified for application requiring higher strength than the low carbon steels such as shafts and gears in automotive field also crankshafts and connecting rods in machinery components. Medium carbon steels are often heat treated to obtain higher strength, such as by quenching and then tempering. Some improvements and developments have been made due to some weaknesses because of low carbon content. Therefore, medium carbon and high carbon steel have more demand in market compare to low carbon steel. It has been known that medium carbon steels are mostly used for simple applications; however, new applications have been developed for which good and better formability is required (Herreraa et al, 2006). Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing.

Table 1: Chemical Composition of AISI 1040 Steel

Element	**C**	**S**	**Mn**	**Fe**	**P**
WT%	0.37-0.44	0.05	0.6-0.9	Balanced	0.04

3.0 Cutting Tool Material

There is such a wide variety of materials used in the metal cutting industry that standards have been established to identify them through a code and colour.

ISO Material Classifications

There is such a wide variety of materials used in the metal cutting industry that standards have been established to identify them through a code and colour.

ISO Class	Material	Notes
P	Steel	Steel is the most common material group, ranging from unalloyed to high-alloyed material including steel castings. The machinability is normally good, but differs depending on material hardness and content.
M	Stainless Steel	Stainless steels are materials alloyed with a minimum of 12% chromium, other alloys can be nickel and molybdenum. Different conditions make this a large family. They all expose cutting edges to a great deal of heat, notch wear and built-up-edge.
K	Cast Iron	Cast iron is a short-chipping type of material. Grey cast iron (GCI) and malleable cast irons (MCI) are quite easy to machine, while others are more difficult. All cast irons contain silicon carbide (SiC), which is very abrasive to the cutting edge.
N	Non Ferrous	Non-ferrous metals are softer types of metals such as aluminum, copper, brass, etc. Aluminum with a silicon content (Si) of 13% is very abrasive. Generally, high cutting speeds and long tool life can be expected.
S	HRSA and Titanium	Heat-resistant super alloys include a great number of high-alloyed iron, nickel, cobalt and titanium-based materials. They are sticky, create built-up-edge, work harden and generate heat. They are difficult to cut and have a short tool life.
H	Hardened Steel	This group covers steels with a hardness between 45-65 HRc and also chilled cast iron around 400-600 HB. The hardness makes them difficult to machine. The materials generate heat during cutting and are abrasive to cutting edges.

The material is significant because:

a. Part material has an influence on the material you choose for your cutting tools
b. Part material and tool material together have an influence on the spindle speeds and feed rates you choose for your machining operations

Figure 2: Tungsten Carbide Cutting Tool

4.0 Failure of Cutting Tools and Tool Wear

Table Showing Three Types of Failure of Cutting Tool

Fracture failure	**Temperature failure**
• Cutting force becomes excessive, leading to brittle fracture	• Cutting temperature is too high for the tool material

Gradual wear

• Gradual wearing of the cutting tool

a. Fracture and temperature failures are premature failures
b. Gradual wear is preferred because it leads to the longest possible use of the tool
c. Gradual wear occurs at two locations on a tool:

Crater wear – occurs on top rake face
Flank wear – occurs on flank (side of tool)

DG Victory IM-5000 Inverted Metallurgical microscope is used to measure the tool wear. The flank wear is observed at 5x and 10x magnification. At both the magnifications the surface features of tool were observed.
Tool wear describes the gradual failure of cutting tools due to regular operation. It is a term often associated with tipped tools, tool bits, or drill bits that are used with machine tools.

Types of wear include:

a. Flank wear in which the portion of the tool in contact with the finished part erodes. Can be described using the Tool Life Expectancy equation.
b. Crater wear in which contact with chips erodes the rake face. This is somewhat normal for tool wear, and does not seriously degrade the use of a tool until it becomes serious enough to cause a cutting edge failure.

Some General effects of tool wear include:

a. Increased cutting forces
b. Increased cutting temperatures
c. Poor surface finish
d. Decreased accuracy of finished part
e. May lead to tool breakage
f. Causes change in tool geometry

Reduction in tool wear can be accomplished by using lubricants and coolants while machining. These reduce friction and temperature, thus reducing the tool wear.

A more general form of the Taylor's equation is

$$v_c T^n = C$$

$$modified, v_c T^n \times D^x S^y = C$$

when,

- $\boldsymbol{v_c}$=cutting speed
- T=tool life
- D=depth of cut
- S=feed rate
- x and y are determined experimentally
- n and C are constants found by experimentation or published data; they are properties of tool material, workpiece and feed rate.

Surface Roughness

Vickers Hardness machine, Model: MHVD-1000AP Surface Roughness Tester was used to determine the average roughness of the machined surface. It is a stylus type surface tester with stylus tip radius of 2µm. The surface roughness was measured for 6 locations and then average all was calculated. Arithmetic Mean Value of Roughness (Ra) was investigated. The surface roughness (Ra) value is calculated for 6 different positions for every experiment and the average is calculated and thus formulated. On the basis Ra value, a plot is plotted showing the different value of average surface roughness for both dry machining and MQL machining.

5.0 Environmental Safety

Machining without the use of any cutting fluid (dry or green machining) is becoming increasingly more popular due to concern regarding the safety of the environment. Most industries apply cutting fluids/coolants when their use is not necessary. The coolants and lubricants used for machining represents 16–20% of the manufacturing costs, hence the extravagant use of these fluids should be restricted. However, it should also be noted that some of the benefits of cutting fluids are not going to be available for dry machining and also dry machining will be acceptable only whenever the part quality and machining times achieved in wet machining are equalled or surpassed.

6.0 Objective

The objective of this research is to:

a. To compare dry and MQL cutting conditions.
b. Predict tool performance.
c. Analyse the performance parameters such as surface roughness, tool wear for dry and near dry machining in order to control the amount of vapour in the working air by applying MQL setup.

7.0 Experimental Investigation

Experiments have been carried out by plain turning a 32 mm diameter and 105 mm length rod of AISI-1040 mild steel in a powerful and rigid lathe (Crusader Lathe Deluxe by Chester UK Ltd) at different cutting velocities (Vc) and feeds (So) under dry, wet and minimum quantity lubrication (MQL) conditions. The machinability characteristics of that work material mainly in respect of cutting temperature, cutting forces, tool wear, surface roughness and dimensional deviation have been investigated to study the role of MQL. The ranges of the cutting velocity (Vc) and feed rate (So) were selected based on the tool manufacturer's recommendation and industrial practices. Depth of cut, being less significant parameter, was kept fixed.

Figure 3: Crusader Lathe Deluxe by Chester UK Ltd

Table 2: Experimental Conditions		
Machine tool	Crusader Lathe Deluxe by Chester UK Ltd	
Work specimen	**Material**	Mild Steel
	Diameter	32mm
	Length	100mm
Cutting Tool	**Manufacturer**	Kyocera Tooling Japan Co.
	Material	Tungsten carbide insert
	Model	TNMG160408
Process parameters		
Environment	Dry, Wet and MQL	
MQL Supply	**Air Pressure**	3 bar
	Lubricant	Micro-emulsion cutting fluid
	Flow Rate	100 ml/hr

9.0 Types and Characteristic of MQL Liquid

The aims in metal cutting are to retain accuracy, to get a good surface finish on the workpiece and at the same time to have a longer tool life. However during the metal cutting process heat is generated due to:

a. the deformation of the material ahead of the tool
b. friction at the tool point

Heat generated due to friction can readily be reduced by using a lubricant. Heat caused by deformation cannot be reduced and yet it can be carried away by a fluid. Thus the use of a cutting fluid will serve to reduce the tool wear, give better surface finish and a tighter dimensional control. The proper selection, mixing and application of cutting fluids is however often misunderstood and frequently neglected in machining practice. In order that the cutting fluid performs its functions properly it is necessary to ensure that the cutting fluid be applied directly to the cutting zone so that it can form a film at the sliding surfaces of the tool.

Cutting fluids in common use

Water It has a high specific heat but is poor in lubrication and also encourages rusting. It is used as a cooling agent during tool grinding. .	**Mineral Oils** They are used for heavier cutting operations because of their good lubricating properties and are commonly found in production machines where high rates of metal removal are employed. Mineral oils are very suitable for steels but should not be used on copper or its alloys since it has a corrosive effect.
Soluble Oils Oil will not dissolve in water but can be made to form an intimate mixture or emulsion by adding emulsifying agents. The oil is then suspended in the water in the form of tiny droplets. These fluids have average lubricating abilities and good cooling properties. Soluble oils are suitable for light cutting operations on general purpose machines where high rates of metal removal are often not of prime importance. There are many forms of soluble oil in the market and the suppliers instruction should be followed regarding the proportions of the `mix'	**Vegetable Oils** They are good lubricants but are of little used since they are liable to decompose and smell badly.

10.0 Dry Machining

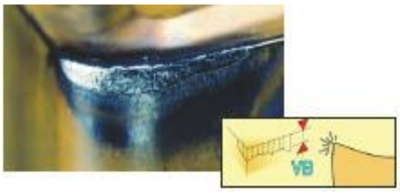
Machining without the use of any cutting fluid (dry or green machining) is becoming increasingly more popular due to concern regarding the safety of the environment. Most industries apply cutting fluids/coolants when their use is not necessary.

Advantage of DryMachining	**Disadvantage of Dry Machining**
a. Low initial cost b. Less maintenance c. Less machining cost	a. Disadvantage of Dry Machining b. Poor surface finish c. High heat development d. Reduced tool life e. High surface roughness f. Chips get welded to the work piece

11.0 Tool Wear under MQL and Dry Machining

Productivity and economy of manufacturing by machining are significantly affected by life of the cutting tools. Cutting tools may fail by brittle fracturing, plastic deformation or gradual wear. Turning carbide inserts having enough strength; toughness and hot hardness generally fail by gradual wears. With the progress of machining the tools attain crater wear at the rake surface and flank wear at the clearance surfaces due to continuous interaction and rubbing with the chips and the work surfaces, respectively. Among the common wears, the principal flank wear is the most important because it raises the cutting forces and the related problems [5].

1 Flank Wear



Abrasive

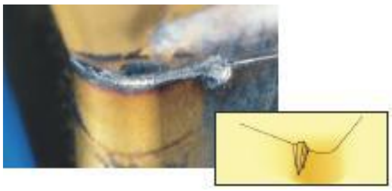
The most common type of wear and the preferred wear type, as it offers predictable and stable tool life. Flank wear occurs due to abrasion, caused by hard constituents in the workpiece material.

2 **Crater wear**

Chemical

Crater wear is localized to the rake side of the insert. It is due to a chemical reaction between the workpiece material and the cutting tool and is amplified by cutting speed. Excessive crater wear weakens the cutting edge and may lead to fracture.

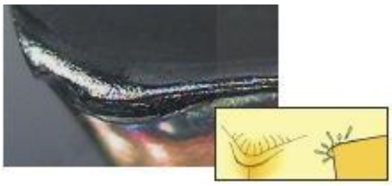
3 **Notch Wear**



Adhesive

Insert wear characterized by excessive localized damage on both the rake face and flank of the insert at the depth of cut line. Caused by adhesion (pressure welding of chips) and a deformation hardened surface. A common wear type when machining stainless steels and HRSA.

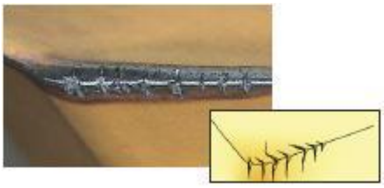
4 **Plastic Deformation**



Thermal

Plastic deformation takes place when the tool material is softened. This occurs when the cutting temperature is too high for a certain grade. In general, harder grades and thicker coatings improve resistance to plastic deformation wear.

5 **Thermal Cracks**



Thermal

When the temperature at the cutting edge changes rapidly from hot to cold, multiple cracks may appear perpendicular to the cutting edge. Thermal cracks are related to interrupted cuts, common in milling operations, and are aggravated by the use of coolant.

6 **Edge Chipping/Breakage**

Mechanic

Chipping or breakage is the result of an overload of mechanical tensile stresses. These stresses can be due to a number of reasons, such as chip hammering, a depth of cut or feed that is too high, sand inclusions in the workpiece material, built-up edge, vibrations or excessive wear on the insert.

Figure 4: Types of Tool Wear In Turning Tools.

12.0 Result and Discussion

Surface Roughness versus Process Parameters

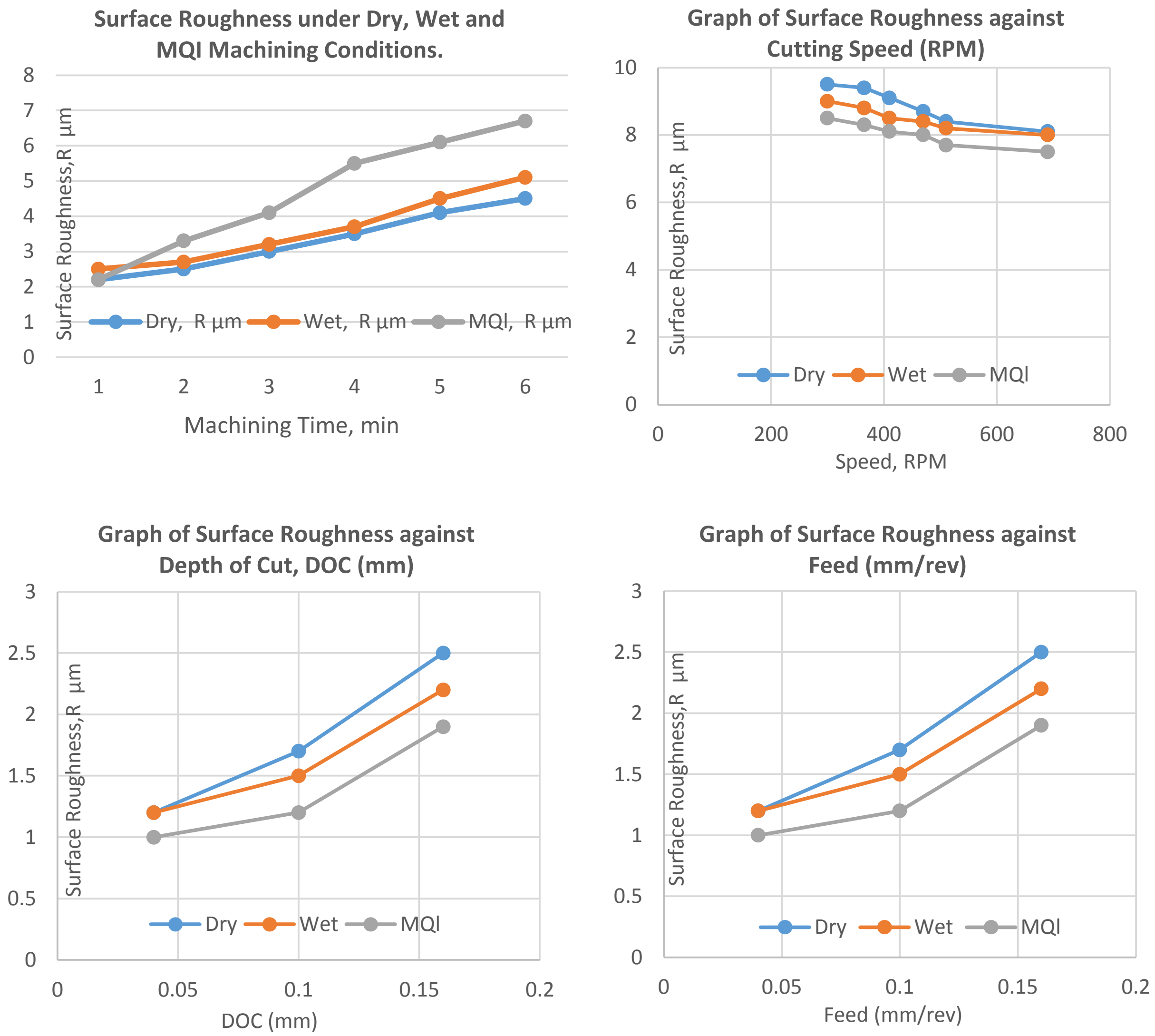


Figure 5: Surface Roughness versus Process Parameters

Arithmetic Mean Value of Roughness (Ra) was investigated. On the basis Ra value, a plot is plotted showing the different value of average surface roughness for dry machining, wet machining and MQL machining. The plots in figure 5 show that the feed has highest impact on surface roughness in both conditions. With increase in cutting speed the surface roughness first decreases and then increases because of the BUE formation at low seed which is higher in dry condition. From these three plots it is evident that with respect to all parameters higher surface finish will be obtained in MQL conditions.

Tool Wear versus Process Parameters

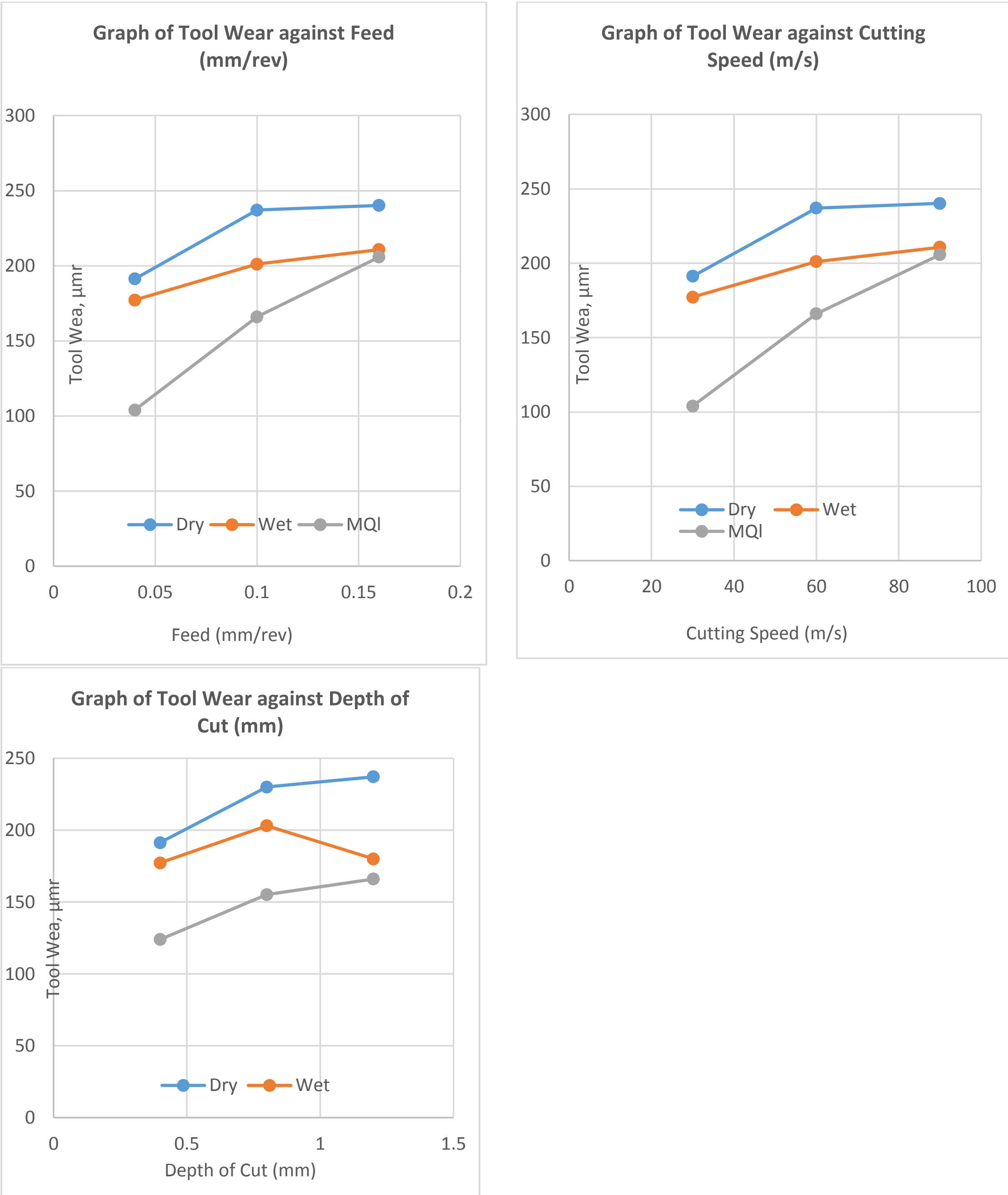


Figure 6: Tool Wear versus Process Parameters

The tool surface is observed under Optical Microscope and values of flank wear were taken. From them average Flank wear was calculated. These values have been tabulated for Dry and MQL setup in. The average flank wear is taken in dry machining, wet machining and compared to corresponding experiment in MQL. Tool wear as shown in plots of figure 6 is less for every experiment in MQL environment. After plotting the tool wear with respect to all the parameters individually in all three conditions it was seen the trend in all conditions was similar and the tool wear was considerably less in case of MQL. Figure 9 clearly represents that in each experiment the flank wear and surface roughness were less in MQL machining as compared to dry and wet machining. Depth of cut is often predetermined by workpiece geometry and operation sequence.

In roughing, depth is made as large as possible to maximize material removal rate, subject to limitations of horsepower, machine tool and setup rigidity, and strength of cutting tool. In finishing, depth is set to achieve final part dimensions**.** In general feed is given first priority and the speed is considered secondly. When tooling is considered harder tool materials require lower feeds. As for roughing or finishing, roughing means high feeds, finishing means low feeds Constraints on feed in roughing is the limits imposed by cutting forces, setup rigidity, and sometimes horsepower. Besides that, surface finish requirements in finishing selects feed to produce desired finish.

Selection of **speed** should achieve a balance between high metal removal rate and suitably long tool life. Mathematical formulas are available to determine optimal speed
Two alternative objectives in these formulas:
a. Maximum production rate
b. Minimum unit cost

15.0 Conclusion

Based on the results of the present experimental investigation the following conclusions can be drawn:

a. The cutting performance of MQL machining is better than that of dry and conventional machining with flood cutting fluid supply because MQL provides the benefits mainly by reducing the cutting temperature, which improves the chip-tool interaction and maintains sharpness of the cutting edges.
b. MQL jet provided reduced tool wear, improved tool life and better surface finish as compared to dry and wet machining of steel.
c. Surface finish and dimensional accuracy improved mainly due to reduction of wear and damage at the tool tip by the application of MQL. Such reduction in tool wear would either lead to improvement in tool life or enhancement of productivity allowing higher cutting velocity and feed.
d. Flank wear in case of MQL is also reduced increasing the life of tool hence the tool cost will reduce.
e. The use of MQL as the flank wear is always less in MQL with respect to individual parameters.

Currently, machines are generally lighter and faster, with less torque, but that can't be combined with depth of cut. Also, with faster speeds while the heat created is intense, each cut can be over very quickly. Ten or 15 years ago on steel the machine would be running 140 to 150m per minute surface speed, wet [i.e. with coolant] but now running more like 230-280mpm, about double the speed, and dry. This high speed also helps avoid damage to the cut surface. Research shows that when one mechanism is to cut really quickly so all the heat stays within the removed metal and doesn't get in to the component. A sharper tool will keep a longer tool life. And it was running faster dry, Another trend to promote dry machining and tool life is carbide technology. Carbide is becoming tougher and tends not to chip but wears. Generally, various producer of gears and shafts, does not apply any coolant because all its machines are fully automated and there is no manual handling of parts, so heat build-up is not an issue.

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