Green Manufacturing in Turning Operation for Efficient Cutting by Application of Vegetable Oil as Cutting Fluid

Thesis submitted in partial fulfillment of

the requirements for the degree of

Master of Mechanical Engineering

By

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KOLKATA – 700032

MAY 2016

Dedicated to my

Parents &

my Favorite

Teachers

CERTIFICATE OF RECOMENDATION

This is to certify that the thesis entitled, "**Green Manufacturing in Turning Operation for Efficient Cutting by Application of Vegetable Oil as Cutting Fluid**", which is being submitted by **Shri Subhadip Das** in the partial fulfillment of the requirements for the award of degree of Master of Mechanical Engineering of Jadavpur University, Kolkata-700032 during the academic year 2014-2016, is the record of student's own work carried by him under the supervision of **Prof. Asish Bandyopadhyay, Prof. Sadhan Kr. Ghosh & Dr. Titas Nandi.**

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This foregoing thesis entitled, "**Green Manufacturing in Turning Operation for Efficient Cutting by Application of Vegetable Oil as Cutting Fluid**" is hereby approved as a creditable study of an engineering subject and presented in a manner satisfactory to warrant acceptance as pre-requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein but Committee on Final examination for evaluation of the thesis approve the thesis only for the purpose for which it is submitted.

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CHAPTER 1

INTRODUCTION

Machining is a manufacturing process in which desired shape, size, accuracy, surface finish and subsurface metallurgy of a job is obtained by removal of excess material from the work piece in the form of chips. These chips are formed by using the M-F-T-W system in which single or multi-point tools are used. A spectacular change has occurred in the material and performance of cutting tools, from stone to diamond and CBN, revolutionizing industries. To stay in the competition industries must deliver customers demand by maintaining standard and quality. To increase the productivity, cutting tool in manufacturing industries should be properly selected.

The material of cutting tool and its geometries play important role on effectiveness, efficiency and overall economy of the machining. The oldest material for making cutting tool was stone. This stone was used to be given the desire shape and sharpness manually. There have been several breakthroughs in last 100 years in development and use of cutting tool material.

A large number of engineering components need reasonably high dimensional and form accuracy along with good surface finish for their functional purpose. Machining is inherently associated with the generation of heat and high cutting temperature at the cutting zone. One of the prime concerns relating to metal cutting is control of generated heat during machining process. The heat is generated is due to friction at chip-tool interface and rubbing action at tool-work piece interfaces. Although majority of heat is carried away by the chip, a significant portion is also transmitted to the tool and the work piece.

The high amount of heat conducted to work piece can damage the surface integrity, change the property of surface and sub-surface layer. A layer of heat-affected zone is formed, which may cause distortion in micro-structure & formation of hardened layer with residual stress just below the machined surface.

Cutting fluids are commonly used to increase the performance of the machining process. This is primarily used for decreasing the friction-induced heat, which is generated during cutting and as a result tool life is increased, surface finish is improved, formation of built-up edges is prevented and transportation of chips is facilitated.

The popular method of cutting fluid application in machining metals is flood cooling. It is considered that flood cooling provides good cooling and lubrication effect. But investigations have revealed that high pressure and small gap existing at chip-tool interface do not allow much of the cutting fluid to penetrate and perform lubricating action by fluid-film lubrication. However, many issues surround the use of cutting fluids, including worker health and safety concerns, fluid system maintenance, fluid pretreatment/ treatment/disposal and environmental concerns.

The increasing demand for comfortable and healthy workplaces for machining industry employees has encouraged manufacturers to implement green machining strategies. In green machining, the word “green” refers to various aspects, such as energy, quality, environmental friendliness, hazard-free properties, time and production costs. Green machining is used to describe products that are made using fewer resources, lower costs, in a maintained healthy environment. For companies, the costs related to cutting fluids represent a large amount of total machining costs. Researchers have found that the costs related to cutting fluids are frequently higher than those related to cutting tools. Moreover, cutting fluids have been found to cause health and social problems for workers, related to lubricant use and correct disposal.

Currently, there is a wide-scale evaluation of the use of metalworking fluids (MWFs) in machining. Industries are looking for ways to reduce the amount of lubricants in metal removing operations due to the ecological, economical and most importantly occupational pressure. From studies, it’s found that respiration and skin problems were the main side effects of MWF. It is, therefore, important to find a way to manufacture products using the sustainable methods and processes that minimize the use of MWFs in machining operations. The first step in implementing these strategies is running the machining process without Metal Working Fluids (MWFs), otherwise known as dry machining.

In addition, it is essential to determine the optimal cutting conditions and parameters, while maintaining long tool life, acceptable surface finish and good part accuracy to achieve ecological and coolant less objective. Many researchers demonstrated successfully a method in the minimization of MWFs called near dry machining (NDM). NDM uses very small amounts of MWF in a flow of compressed air that can be approximately 1000 times less than conventional flood cooling. Another name of this process is Minimum Quantity Lubrication (MQL).

In this study coated inserts have been used to turn AISI 1055 steel under three different cutting conditions, and flank wear of the tool and surface roughness of the work piece have been studied.

1.1. Turing

This is the very basic operation which can be performed on a lathe to produce a cylindrical surface. A flat surface can be obtained through face turning. Fig 1.1 shows a typical turning operation where a work piece in the form of a cylindrical bar is rotated about it axis. The tool is provided with a feed motion parallel to the machine surface. This operation results in a reduced work diameter and a new cylindrical surface. The tool used for the operation is generally known as single point turning tool.

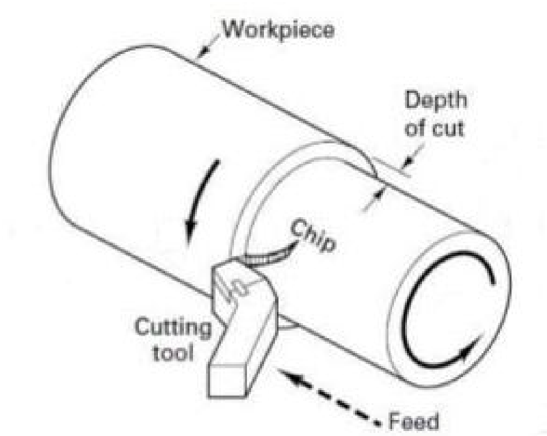


Fig 1.1. Typical turning operation

The Machining performance depends on the following:

- Cutting tool
- Workpiece material

- Application of Cutting fluids
- Machining condition
- Machine tool

The effect of different parameters is shown in the Fig.1.2.

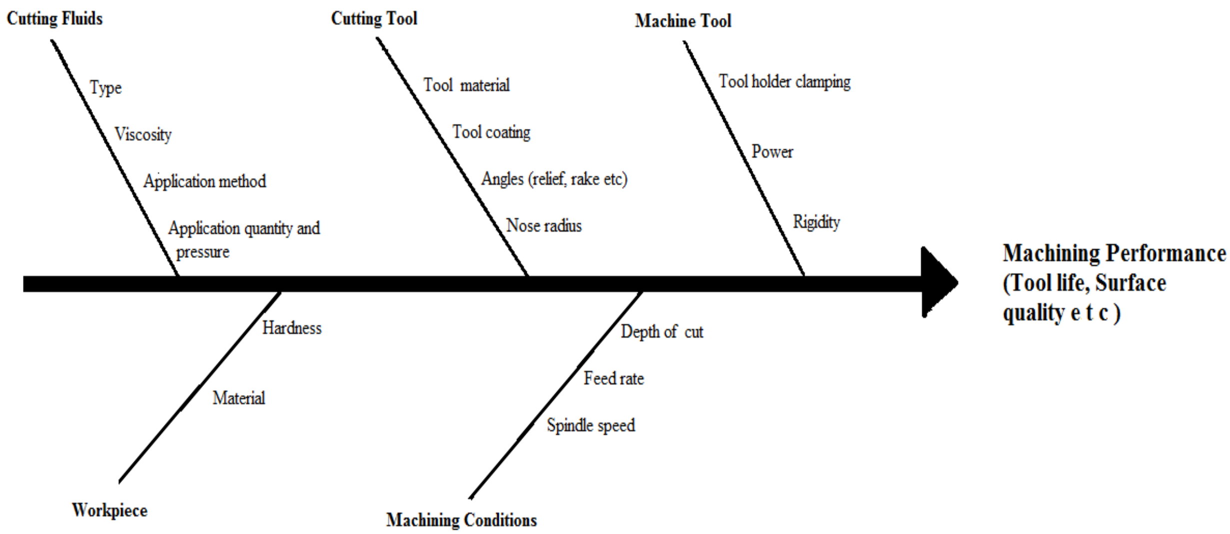


Fig 1.2. Effect of machining parameters on machining performance

1.2. Cutting Tool

A cutting tool is any tool that is used to remove materials from the work piece by shear deformation. Both the materials and the geometry of cutting tools play very important roles on the performance in terms of achieving efficiency and overall economy of machining.

Cutting tools may be classified as

1. Single-point tools: Used in turning, shaping, planing and slotting, boring operations. Tool geometry of Single-point cutting tool is shown in Fig 1.3.

2. Double –point or two-point tools: Drill bits are two-point cutting tools.

3. Multi-point tools: Milling cutters, broaching tools, hobs, gear shaping cutters, grinding wheels etc. are multi-point cutting tools.

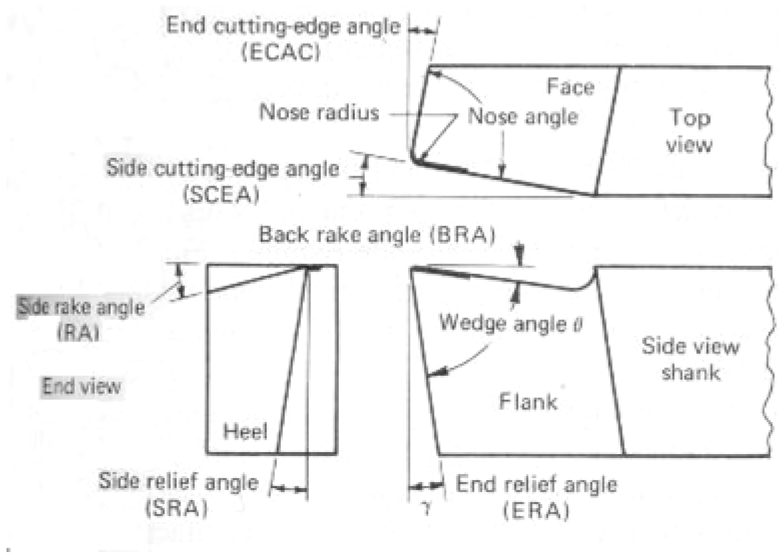


Fig 1.3. Tool geometry of a single point tool

The basic principle of machining by gradual removal of work material in the form of chips is more or less same for all cutting tools, where the sharp wedge shaped cutting edge is forcibly pushed against the work material, as shown in Fig 1.4.

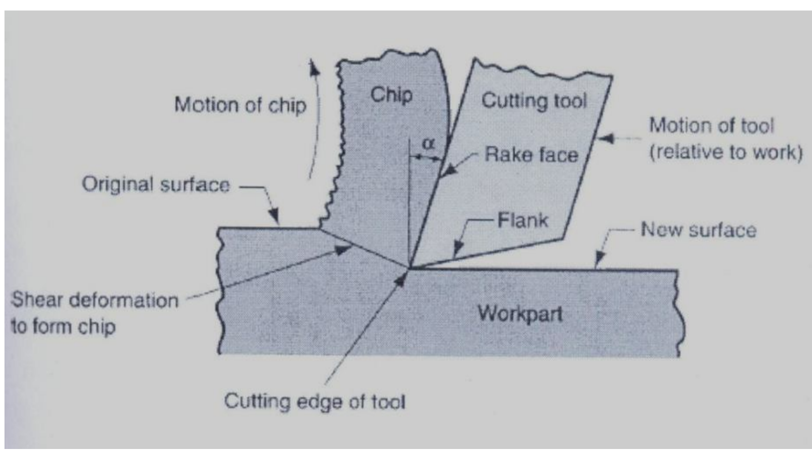


Fig 1.4. Relative motions between tool, work piece and chip

1.2.1. Cutting tool materials

The vast program in industrial manufacturing has brought about several remarkable improvements in cutting tool materials and geometry

- to meet the ever-growing demands for enhanced productivity, high quality and overall economy of machining.
- to enable effective and efficient machining of the difficult-to machine exotic materials which are rapidly and widely coming up with the progress of the industrial world.
- to accomplish precision and ultra- precision machining as per demands of the day and future.
- for micro-machining as its demand is increasing.

The service life and overall performance of cutting tools, for a given job, are governed by:

- Materials of the cutting tools.
- Geometry of the cutting tools.
- The condition of machining and cutting fluid application.

For preventing of random and catastrophic failure of the cutting edges by breakage, rapid plastic deformation and for retention of sharpness for long life of the tools, cutting tool materials essentially require the following properties:

1. High mechanical strength to resist breakage of the tool.
2. High hardness to reduce abrasion wear.
3. High hot hardness to maintain form stability of the cutting edges.
4. Adequate fracture toughness and transverse rupture strength to reduce chipping and fracturing.
5. Enough fatigue strength to withstand dynamic loading.
6. High chemical stability or inertness against work materials, atmospheric gases and cutting fluid.
7. Reasonably high thermal conductivity to reduce cutting temperature at the tool tip.
8. Resistance to adhesion and diffusion to retard adhesion wear and the rapid diffusion wear.
9. High stiffness to maintain dimensional accuracy of the machined features.
10. Self-lubricity or lesser friction at the chip-tool interface to resist formation of built up edge.
11. Formability, availability and inexpensiveness.

An overview of the existing tool materials can be enumerated as follows

1. **Carbon Tool Steel:** The chief characteristics of carbon tool steels are low hot hardness and poor hardenability. A typical composition of carbon tool steel has 0.8% to 1.3% Carbon, 0.1 to 0.4% Silicon, 0.1 to 0.4% Manganese and rest Iron. The higher the carbon content the greater will be the hardness and the wear resistance.

2. **High Speed Steel (HSS):** There are different types of HSS and the most frequently used one is basic HSS. The composition of basic HSS is 18% Tungsten, 4% Chromium, 1% Vanadium, 0.7% Carbon and the rest being Iron. After its inception HSS was used as a chief tool material because of its hot hardness and ability to operate at high cutting speed in comparison to Carbon tool steel. With the introduction of advanced cutting tools, HSS might have lost it usage but is still a commonly used tool in conventional cutting.

3. **Stellite:** This is a cast alloy of Cobalt, Tungsten and Carbon. Stellite is quite tough and is more heat and wear resistive than the basic HSS.

4. **Ceramics:** Inherently high compressive strength, chemical stability and hot hardness of ceramics have led to powder metallurgical production and use of indexable ceramic tool insert since 1950. Alumina (Al_2O_3) and Silicon Nitride (Si_3N_4) are the two basic ceramics suitable for cutting tools.

5. **Cemented Carbide:** Around 1928, Tungsten Carbide was developed in Germany. Originally, finely ground Tungsten Carbide (WC) particles were sintered together with cobalt binder. This material in early stage was brittle, difficult-to-grind and had tendency to cause adhesion crater when machining steels. Such tool is mainly used to machine cast iron. TiC and TaC have been found to be more stable than WC and have greater resistance to decomposition in presence of FCC γ–iron. TaC provides greater crater resistance with less loss of impact strength than TiC since it gives rise to less gain growth during sintering.

The variation of hardness of cutting tool with temperature is shown in Fig 1.5.

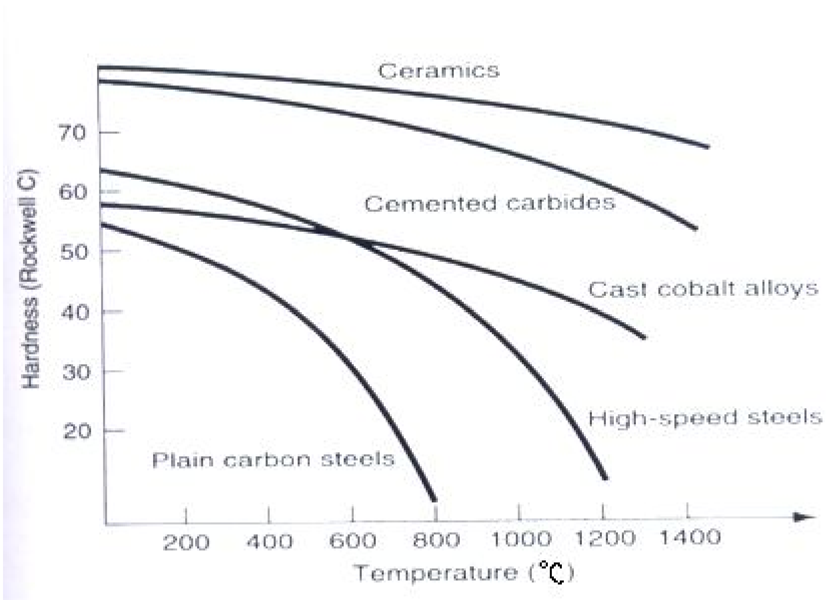


Fig 1.5. Variation of hot hardness with temperature [44]

1.2.1.1. Cemented Carbides

Three types of Cemented Carbides are normally used. The first one which is known as single carbide contains WC and Cobalt as binder. These cannot be used for machining steel though it has a good bending strength. The double carbide contains Tungsten Carbide, Titanium Carbide and Cobalt, and it has low bending strength but the problem of adhesion crater is removed. For cutting steel the triple carbide or steel cutting grade carbide was developed by powder metallurgy technique having Tungsten Carbide (WC), Titanium Carbide (TiC), Tantalum Carbide (TaC) and Cobalt (Co) in it. It has good bending strength as well as no adhesion crater during machining steel.

Cemented Carbides are produced by Powder Metallurgy. The carbide tools are made in the form of inserts as shown in Fig 1.6. Usually carbon tool steel shank is used where the insert is placed and the different angles are provided on the tool holder.

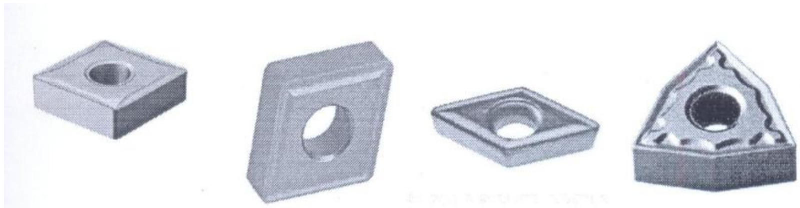


Fig 1.6. Some uncoated carbide insert

The general characteristics of Carbide tools are as follows [46]:

1. High hardness over a wide range of temperature (up to 900^0C).
2. Very stiff (Young's modulus is about three times that of steel).
3. Low thermal expansion when compare to steel.
4. High thermal conductivity.
5. Low specific heat.
6. Weaker in tension than in compression.

1.2.1.2. Coated Carbide Inserts

To increase the life of Carbide tools, they are sometimes coated. Four such coating are TiN (Titanium Nitride), TiC (Titanium Carbide), TiCN (Titanium Carbide Nitride) and TiAlN (Titanium Aluminium Nitride). Most coating generally increases a tool's hardness and lubricity. A coating allows the cutting edge of a tool to cleanly pass through the material without having the material stick to it. The coating also helps to decrease the temperature associated with the cutting process and increase the life of the tool.

Chemical Vapour Deposition (CVD) and Physical Vapour Deposition (PVD) are the two main coating processes for carbide inserts. CVD coatings are thick (typically 9-20 microns) and highly wear resistant, making then especially useful for steel and cast iron machining as well as widely used in turning operation. PVD coatings are thin (typically 2-3 microns) yet tougher and typically smoother than CVD one. Consequently, they are useful for machining materials, such as super alloy, titanium alloys and difficult to machine stainless steels, that typically notch or chip cutting edges. CVD coated inserts work well in turning, milling and drilling applications involving ferrous materials. PVD coated inserts are especially useful turning, milling and drilling applications involving high temperature alloys, titanium alloys and stainless steel . PVD coated inserts are recommended when turning high temperature alloys, whereas for turning, milling or drilling steels and cast irons, CVD coated inserts are recommended over PVD coated inserts. Some shapes of Coated Carbide are shown in Fig 1.7.

Fig 1.7. Some type of coated carbide insert

1.3. Workpiece Material

Plain carbon steels are available in the form of bar, tube, plate, sheet and wire. When carbon percentage of the steel is more than 0.5%, it's known as high carbon steel. High carbon steels respond readily to heat treatments. When heat treated, high carbon steels have very high strength combined with hardness. They do not have much ductility as compared with low and medium carbon steels. High carbon steels are difficult to weld. Excessive hardness is often accompanied by excessive brittleness.

AISI 1055

AISI 1055 is tougher and respond readily to heat treatment. Therefore, it is selected for components gears, machine tool spindles, transmission shafts, sprockets, cylinders, cams, crankshafts, keys, small gears, machine tools components, grinding balls for ball mills, bolts, nuts, pulleys etc.

The Mechanical properties of AISI 1055 steel are:

Tensile strength	720 N/mm^2
Yield strength	460 N/mm^2
Hardness (HB)	265
Elongation	13 %

1.4. Cutting Fluid

Though in a large number of cases machining can be conducted in a dry condition, quite often the use of a cutting fluid is very effective for improving the overall machinability. A suitably chosen fluid may reduce the coefficient of friction at the interfaces.

A cutting fluid affects machining in the following ways:

1. Cooling down of the chip-tool-work zone by carrying away some of the generated heat.
2. Reducing the coefficient of friction at the chip-tool interface due to the formation of a weaker compound at the interface.
3. Reducing the thermal distortion caused by temperature gradients generated during machining.
4. Washing away the chips and clearing the machining zone.
5. Protecting the finishing surface from corrosion.

Cooling down obviously increases the tool life and reduces the thermal distortion. A reduction in the coefficient of friction lowers the machining force and power consumption. This also prevents the formation of BUE and the surface finish improves greatly. Washing away of the chips is very helpful in cases where chips are very small as in grinding and milling.

An ideal cutting fluid should have following properties [45]:

- A large specific heat and thermal conductivity,
- A low viscosity and small molecular size (to help rapid penetration to the chip-tool interface),
- Contain a suitable reactive constituents (for forming a low strength compounds after reacting with the work material),
- Nonpoisonous and noncorrosive,
- Inexpensive and easily available.

There is a wide variety of cutting fluids available today. Mainly the cutting fluids are two types, (i) water based fluids and (ii) mineral oil based fluids. The goal of machining operations must be to improve productivity and reduce costs. This is accomplished by machining at the highest cutting speed while maintaining long tool life, reducing scrap and producing parts with the desired surface quality. Proper selection and use of cutting fluids can help to achieve all of these goals. Now additives are added with cutting fluids to accomplish the goal of machining [42].

1.4.1. Vegetable oils and lubricants

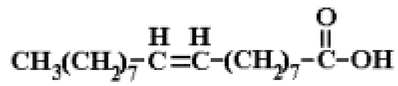
Over the past two decades, a renewed interest in vegetable oil-based lubricants has occurred as interest on environmental pollution matters has increased. Vegetable oils can have excellent lubricity, far superior than that of mineral oil. Vegetable oils also have a very high Viscosity Index (VI); for example, 223 for soyabean oil against 90 to 100 for most petroleum oils. It is stated that the viscosity of oil with high VI changes less than that of an oil with low VI for a given temperature change. It is found that mineral oil with the same viscosity is not as effective as a lubricant in comparison to the vegetable or animal based oil. This improved property of the vegetable or animal oils and fats called oiliness or lubricity.

Vegetable oils have high flash/fire points. For example, 610°F (326°C) is the flash point of soyabean oil compared to a flash point of approximately 392°F (200°C) for mineral oils. Most importantly, vegetable oils are biodegradable, in general less toxic, renewable and reduce dependency on imported petroleum oils.

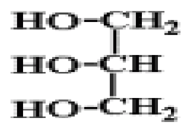
1.4.2. Chemical composition of vegetable oils

All crude vegetable oils contain some natural elements like gummy and waxy matter that may interfere with the stability, hydrocarbon solubility, chemical transformation reactions and freezing point. Therefore, a purification step is required to obtain refined vegetable oils that are completely miscible with hexane. Refined vegetable oils are largely glycerides of the fatty acids.

Triglycerides are the main constituents of vegetable oils and animal fats. Triglycerides have lower densities than water (they float on water) and at normal room temperatures may be solid or liquid. When solid, they are called "fats" or "butters" and when liquid they are called "oils". A triglyceride, also called triacylglycerol (TAG), is a chemical compound formed from one molecule of glycerol and three fatty acids.

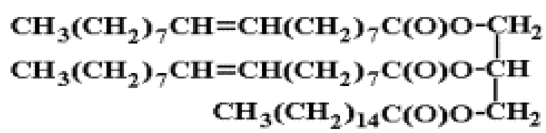


Oleic Acid



Glycerol or Glycerin

Glycerol is a trihydric alcohol (containing three **-OH** hydroxyl groups) that can combine with up to three fatty acids to form monoglycerides, diglycerides and triglycerides. Fatty acids may combine with any of the three hydroxyl groups to create a wide diversity of compounds. Monoglycerides, diglycerides and triglycerides are classified as *esters* which are compounds created by the reaction between acids and alcohols that release water (**H_2O**) as a by-product.



Trigycerides [50]

The most important characteristic of vegetable oil is its biodegradability. Biodegradability means that a substance is susceptible to biochemical breakdown by the action of microorganism.

By more readily biodegradable it is meant that the fluids, using standard methods and process, are converted from the lubricating fluids to lower molecular weight components that have essentially no environmental impact. The rate at which lubricants and other chemicals or additive components, are biodegrade is related to their chemical structure. Hydrocarbons are broken down into carbon dioxide and water by naturally occurring bacteria in soil and water. Since biodegradability is environment dependent, substances which readily degrade under one set of conditions may persist under others. In order for biodegradation to occur, there must be sufficient bacterial population, adequate oxygen and suitable ambient temperature. The source of food for the bacteria is the oil itself, but an excess of oxygen must be present for a reasonable rate of biodegradation to take place. Complete biodegradability indicates the lubricant has essentially returned to nature. Partial biodegradability usually indicates one or more component of the lubricant is not degradable.

Important properties of vegetable oils as cutting fluids are (i) Melting or Freezing point for workability (ii) Smoke point, the temperature at which the oil is decomposed and where possibly toxicological relevant compounds are formed (iii) Specific heat and thermal conductivity for carrying off generated heat away from the cutting zone (iv) Peroxide value, measure of decomposition of oil and oxidative rancidity (v) Acid Number, indicates free fatty acid content in oil, higher value signifies more potential corrosion activator (vi) Iodine Number, a measure of degree of unsaturation in fatty acids and influences oxidative rancidity and chemical stability of oil [42].

1.5 Surface roughness in Turning

Surface roughness is the micro irregularity on the surface. Good surface finish is demanded from the time when man used sharp wooden sticks and stones for hunting and self-protection. Nowadays, good surface finish is demanded in industrial as well as daily life. Manufacturers have given attention to the daily increasing surface finish quality. Surface finish is a never-ending topic which needs better and better investigations- both experimental and analytical.

1.5.1 Statistical Description of Roughness

Surface roughness is characterized by three different types of roughness parameters, viz., amplitude parameters, spacing parameters and hybrid parameters. Amplitude parameters are the measure of vertical characteristics of surface roughness deviation center line average surface roughness, root mean square roughness etc are the examples of these types of roughness. Spacing parameters are measures of horizontal characteristics of surface deviations. Examples of such parameters are mean line peak spacing, high spot count etc. on the other hand, hybrid parameters are the combination of both vertical and horizontal characteristics of surface deviations e.g. root mean square slope of the profile, root mean square wavelength, peak area, valley etc.

1.5.2 Center line average (CLA) value or R_a value

It is defined as the arithmetic mean deviation of the surface height from the mean line through the profile. It is also termed as average roughness (R_a). Here the mean line is defined so as to have equal areas of the profile above and below it. It may also be defined by the equation:

$$Ra = \frac{1}{L}\int_0^L |Z(x)|\,dx \tag{1}$$

where, R_a = the arithmetic average deviation from the mean line, L= the sampling length

Fig 1.8 shows the various elements in relation to surface roughness.

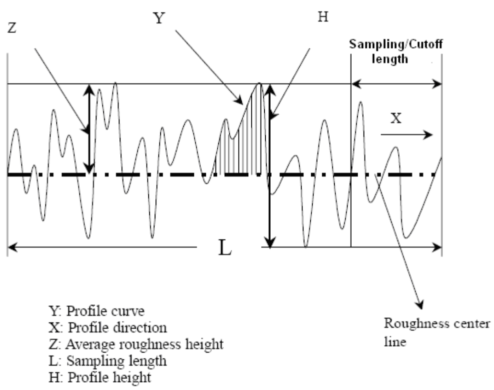


Fig 1.8. Surface roughness profile

Fig 1.9 depicts that the surfaces having different profiles over the same sampling length with the same R_a value.

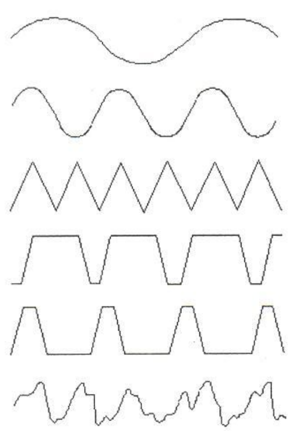


Fig 1.9. Various surface profiles having same R_a value

1.5.3 Factors affecting surface roughness

The factors that have the main influence on surface roughness in machining are:

1. The depth of cut

The depth of cut influences surface quality in an indirect way. Increasing the depth of cut increases the cutting resistance and the amplitude of vibrations. Cutting temperature also rises. Therefore, it is expected that surface quality will deteriorate.

2. The feed rate

Experiments show that as feed rate increases surface roughness also increases. In any case, lowering feed rates below a certain limit does not yield any substantial improvement in surface quality.

3. The cutting speed

In the cases of turning cutting speed plays an important role as, an increase of cutting speed generally improves surface quality.

4. The cutting tool wear

The irregularities of the cutting edge due to wear are reproduced on the machined surface. Apart from that, as tool wear increases, other dynamic phenomena such as excessive vibrations will occur further deteriorating the surface quality.

5. The use of cutting fluid

The cutting fluid is generally advantageous in regard to surface roughness because it affects the cutting process in three different ways. Firstly, it abstracts the heat that is generated during cutting by cooling mainly the tool point and the work surface. In addition to this, the cutting fluid is able to reduce the friction between the rake face and the chip as well as between the flank and the machined surface. Lastly, the washing action of the cutting fluid is not to be underestimated as it consists in removing chip fragments and wear particles. Therefore, the quality of a surface machined with the presence of cutting fluid is expected to be better than that obtained from dry cutting.

6. The three components of the cutting force

It should be noted that force values cannot be set a priori, but are related to other factors of the experiment as well as to factors possibly not included in the experiment, i.e. force is not an input factor and is used as an indicator of the dynamic characteristics of the work piece cutting tool machine system.

1.5.4 Measurement of surface roughness

A stylus type profilometer (Fig 1.10.) consists of diamond headed stylus which is connected to the transducer. The transducer moves along its length by means of a motor and gearbox mechanism which gives the rectilinear motion of the stylus. The measured data in terms of analog signal is fed into an amplifier which amplifies the signal so as to the signal can be converted to digital signal by a analog to digital (A-D) converter. Chart recorder takes amplified signal from the amplifier for further work.

Surface roughness of a machined product could affect several of the product's functional attributes such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating, and resisting fatigue. Therefore, surface roughness becomes one of the important quality aspects in milling products.

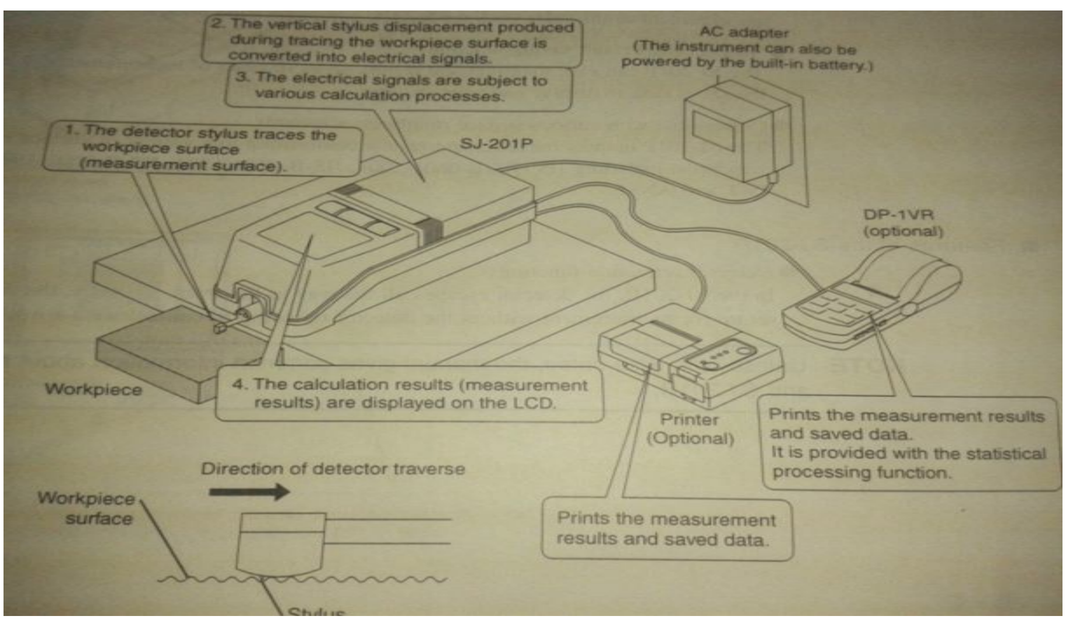


Fig 1.10. Schematic diagram of portable surface roughness tester

There are various simple surface roughness parameters used in industries, such as roughness average (R_a), root mean square roughness (R_q), and maximum peak to valley roughness (R_{max}), etc. The parameter R_a is used in this study. The average roughness (R_a) is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length.

1.6 Tool Wear and Tool Life in Turning

The life of a cutting tool can be terminated by a number of means, although they fall broadly by three main categories:

1. Mechanical breakage
2. Loss of form stability at elevated temperature
3. Gradual wear of certain regions of the face and flank of the cutting tool

The first two causes can be controlled by selecting proper tool material with proper tool geometry and cross-section of the tool. But the third one is obvious and tool mainly fails due to this reason even though proper material is selected. Considering this, the life of a cutting tool is, therefore, determined by the amount of wear that has occurred on the tool surfaces and which reduces the efficiency of cutting to an unacceptable level, or eventually causes tool failure.
When the tool wear reaches an initially accepted amount, there are two options,

- to resharpen the tool on a tool grinder, or
- to replace the tool with a new one.

This second possibility applies in two cases, (i) when the resource for tool resharpening is exhausted. or (ii) the tool does not allow for resharpening.

1.6.1 Wear zones

Gradual wear occurs at three principal locations on a cutting tool. Accordingly, three main types of tool wear are:

- Crater wear
- Flank wear
- Corner wear

1.6.1.1 Crater wear:

When the chip flows over the rake surface of the tool, due to continuous rubbing action between the chip and the tool, tool material is removed from the rake surface of the tool at a distance from the tip of the tool. Crater wear affects the mechanics of the metal cutting process by increasing the actual rake angle of the cutting tool. At the same time, the crater wear weakens the tool by changing the tool rake angle and increases the possibility for tool breakage. To reduce crater wear chip breaker is provided on the rake surface.

1.6.1.2 Flank wear:

Flank wear occurs on the tool flank as a result of friction between the machined surface of the work piece and the tool flank. Flank wear appears in the form of so-called wear land and is measured by the height of this wear land (V_B). Flank wear affects to the great extent the mechanics of cutting. Cutting forces increase significantly with flank wear.

1.6.1.3 Corner wear:

Corner wear occurs on the tool corner, near the nose of the tool. It can be considered as a part of the wear land since there is no distinguished boundary between the corner wear and flank wear land. Corner wear actually shortens the cutting tool thus increasing gradually the dimension of machined surface and introduce a significant dimensional error in machining, which can reach values of about 0.03~0.05 mm.

These three wear types are illustrated in the Fig 1.11. and Fig 1.12.

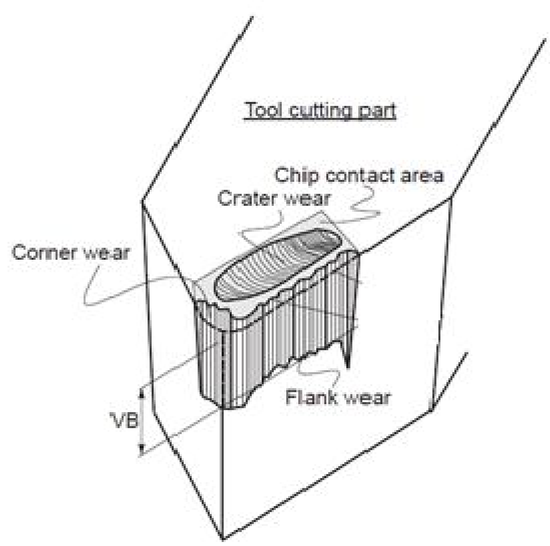


Fig 1.11. Types of wear observed in cutting tool

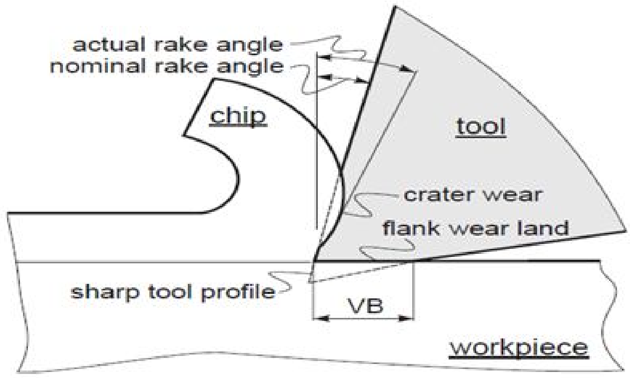


Fig1.12. Flank wear and crater wear of a single point tool

In metal cutting, three basic causes have been suggested for tool wear

i) Adhesion: when two matting surfaces come in close contact, strong bonds are formed due to welding of surface asperities. If the bonds formed at the asperity junctions are stronger than the local strength of the material, particles may transfer from one surface to the other when the junctions fracture. Thus small fragments of tool material can get torn out and get carried away on the underside of chip or on the surface of work piece.

ii) Abrasion: when two surfaces are sliding contact, the surface asperities of the harder material plough a series of grooves on the softer material. Alternatively material removal may be caused by loose hard particle trapped at the sliding interface. Thus hard particles on the underside of chip or loose hard particles trapped at the chip-tool interface may remove tool material due to abrasion.

iii) Diffusion: In metal cutting, close contact occurs at chip-tool and tool-work interfaces along with high temperatures. Thus diffusion can occur and atoms from tool material may diffuse into work material or the chip causing weakening of surface structure of the tool material.

1.6.2 Wear control:

As it has been discussed earlier, the rate of tool wear strongly depends on the cutting temperature; therefore, any measures which could be applied to reduce the cutting temperature would reduce the tool wear as well. Fig 1.13. shows the process parameters that influence the rate of tool wear:

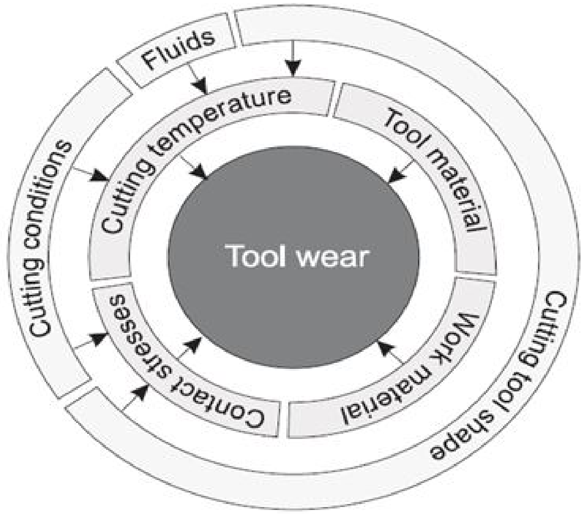


Fig 1.13. Effect of basic process parameter on cutting tool wear

Additional measures to reduce the tool wear include the application of advanced cutting tool materials, such as coated carbides, ceramics, etc.

1.7 Tool Life

There are various ways in which the tool life can be specified, e.g., cutting time to failure, cutting length to failure etc. Similarly, there are various ways in which tool failure can be identified, e.g., wear land size, depth of crater, tool wear volume, surface finish value etc. It is obvious that the tool life value will depend on tool failure criterion used [45].

1.8 Optical Microscope

The optical microscope, often referred to as light microscope, is a type of microscope which uses visible light and a system of lenses to magnify images of small samples. Optical microscopes are the oldest design of microscope and were possibly invented in their present compound form in the 17th century. Basic optical microscopes can be very simple, although there are many complex designs which aim to improve resolution and sample contrast.

All modern optical microscopes designed for viewing samples by transmitted light share the same basic components (basic optical transmission microscope elements) of the light path. . In addition, the vast majority of microscopes have the same 'structural' components. An optical microscope is shown in Fig 1.14.

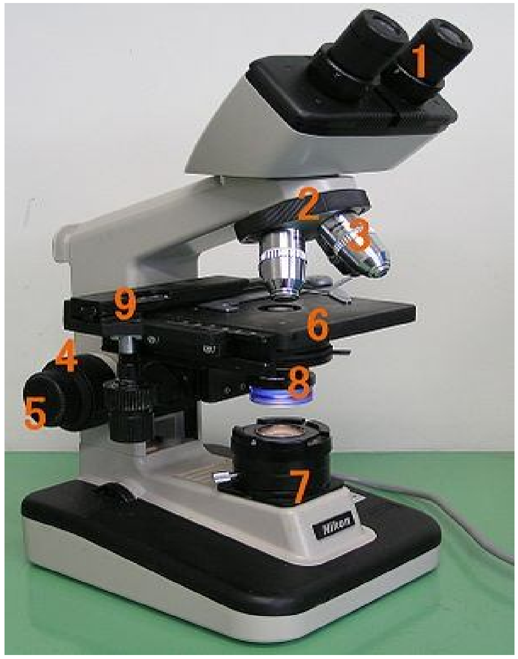


Fig 1.14. Optical microscope

- Eyepiece (ocular lens) (1)
- Objective turret, revolver, or revolving nose piece (to hold multiple objective lenses) (2)
- Objective lenses (3)
- Focus knobs (to move the stage)
    - Coarse adjustment (4)
    - Fine adjustment (5)
- Stage (to hold the specimen) (6)
- Light source (a light or a mirror) (7)
- Diaphragm and condenser (8)
- Mechanical stage (9)

The actual power or magnification of a compound optical microscope is the product of the powers of the ocular (eyepiece) and the objective lens. The maximum normal magnifications of the ocular and objective are 10X and 100X respectively, giving a final magnification of 1,000X.

1.9 Literature Review

Before carrying out the research work, it is necessary to have some knowledge about the previous investigations and research in the proposed area of research.

Chinchanikar & Choudhury [1] have carried out an investigations on tool wear progressions for tools coated with HiPIMS (High Power Impulse Magnetron Sputtering) coating technique, namely, nanocomposite AlTiN, nanocomposite multi-layer TiAlN/TiSiN and nanocrystalline AlTiCrN to hard turning of AISI 4340 heat treated steel (55 HRC) and to address minimum quantity liquid application method.

Kamata and Obikawa [2] have applied MQL to finish-turning of a nickel-base superalloy, Inconel 718, with three different types of coated carbide tools. The coatings are TiCN/Al_2O_3/TiN (CVD), TiN/AlN superlattice (PVD) and TiAlN (PVD). Cutting speeds have been set at relatively higher values: 1 and 1.5 m/s.

Hadad & Sadeghi [3] have carried out an experiment to study the effects of cutting parameters (cutting speed, depth of cut and feed) on turning performance. In this experiment they have used cutting fluid, cutting tool & work piece as Ester oil, HSS tool & AISI 4140 respectively.

Khan *et al.* [4] have evaluated the effects of minimum quantity lubrication (MQL) by vegetable oil-based cutting fluid on the turning performance of low alloy steel AISI 9310 and uncoated carbide as compared to completely dry and wet machining in terms of chip–tool interface temperature, chip formation mode, tool wear and surface roughness, and minimum quantity lubrication has been provided with a spray of air and vegetable oil.

Liu *et al.* [5] have investigated the wear rate, wear pattern and wear mechanism in turning operation of two kinds of nano composite coatings,(nc-AlTiN)/(a-Si3N4) and (nc-AlCrN)/ (a-Si3N4) with titanium alloy, in dry and MQL conditions.

Leppert [6] has investigated on the influence of cutting zone cooling with help of cutting fluid Accu-Lube LB8000 biodegradable vegetable oil on surface roughness and waviness after turning C45 steel with Carbide insert SNMG 120408-TF. Dry cutting and minimum quantity lubrication

(MQL) results have been compared with conventional emulsion cooling. Cutting forces and their components have been put under examination as well.

Krishna *et al.* [7] have studied on the application of nanosolid lubricant suspensions in lubricating oil in turning of AISI 1040 steel with carbide tool. SAE-40 and coconut oil have been taken as base lubricants and boric acid solid lubricant of 50 nm particle size as suspensions. Variation of cutting tool temperatures, average tool flank wear and the surface roughness of the machined surface with cutting speed and feed have been studied with nanosolid lubricant suspensions in lubricating oil.

Settineri *et al.* [8] have developed nanostured coating coatings, TiN+AlTiN, TiN+AlTiN+MoS2 and CrN+CrN:C+C, applied by PVD techniques on WC-Co inserts, for continuous cutting of nickel-based super-alloys, in Minimum Quantity Lubrication (MQL) with commercial lubrication and dry. Results have been analysed in light of the outcome of machining experiments performed mainly in dry and MQL turning of Inconel 718.

Obikawa *et al.* [9] have described MQL machining in a range of oil consumption less than 1.0 ml/h, which is 10–100 times smaller than the consumption usually adopted in industries. MQL machining in this range is called micro-liter lubrication machining. A specially designed nozzle has been used for concentrating small amounts of oil mist onto the cutting interface. The performance of concentrated spraying of oil mist in micro-liter lubrication machining of Inconel 718 with Coated carbide inserts with multiple CVD coatings of $TiCN/Al_2O_3/TiN$ has been investigated and compared with that of ordinary spraying.

Bruni *et al.* [10] have focussed on the effects produced by cutting operations on work piece surface finish and tool wear. They have carried out turning operation of AISI 420B stainless-steel under wet, minimum quantity of vegetable cutting fluid medium and dry cutting conditions, using both conventional and wiper technology inserts on carbide tools.

Paulet *et al.* [11] have experimented on turning operation under dry, wet and mql condition and selected w/p and cutting tool as AISI 4340 and carbide tool coated with TIC and TICN. In this study, tool wear and surface roughness have been studied.

Dhar *et al.* [12] have investigated on the role of MQL on tool wear and surface roughness in turning AISI-4340 steel at industrial speed-feed combination by uncoated carbide insert.

Banerjee and Sharma [13] have developed of a friction model as a function of the cutting speed and tool feed rate when machining with minimum quantity lubrication. In this study they have carried out a turning operation Combination of cutting tool (Carbide insert SNMG 120408-TF, grade IC907, PVD coating composition TiAlN Coating) with workpice AISI 1045 under cutting fluid Accu-Lube LB 8000 oil.

Davis *et al.* [14] have investigated the effectiveness of ionic liquid (IL), a low melting point salt, as a lubricant additive for minimum quantity lubrication (MQL) implementation during titanium machining with cubic boron cutting tool. Here in 1-butyl-3-methylimidazolium hexafluoro phosphate(BMIM-PF6), a prototypical IL, has been used as an MQL cutting fluid additive.

Sreejith [15] has analyzed the effect of dry machining, minimum quantity of lubricant (MQL) and flooded coolant conditions during machining of 6061 aluminium alloy with diamond-coated carbide tools with respect to the surface roughness of the machined work-piece and tool wear.

Zhiqiang *et al.* [16] have studied on turning of TC9 titanium alloy with Uncoated carbide, K30 grade under three cooling method (cold water mist jet (CWMJ), cold air jet and flood cooling).

Sarıkaya & Güllü [17] have investigated the effect of the main turning parameters such as cooling condition, cutting speed, feed rate and depth of cut on arithmetic average roughness (Ra) and average maximum height of the profile (Rz) when turning of AISI 1050 steel with TiAlN coated carbide. Experiments have been performed under dry cutting (DC), conventional wet cooling (CC) and MQL. Mathematical models have been created for surface roughness, namely R_a and R_z, through response surface methodology (RSM).

Elmunafi *et al.* [18] have evaluated the performance of coated carbide cutting tools in term of tool life under MQL with flow rate of 50 ml/h using castor oil as the cutting fluid. The experiment has been conducted with hardened AISI 420 stainless steel (with 47 – 48 HRC hardness) as work piece material. Empirical models for tool life as a function of cutting speed and feed has been developed within the range of cutting parameters evaluated.

Zel & Karpat [19] have developed a predictive modeling on surface roughness and tool wear in hard turning using regression and neural network. The objective of this study was the development of models, based on feed forward neural networks for predicting accurately both surface roughness and tool flank wear in turning operation. The experimental data of measured surface roughness and tool flank wear have been used to train the neural network models.

Debnath *et al.* [20] have investigated about the developments in bio-based cutting fluids by using various vegetable oils which have significantly reduced the ecological problems caused by mineral based cutting fluids. They have discussed about the green manufacturing methods like use of vegetable based cutting fluids, minimum quantity lubrication, cryogenic cutting and there are some of the sustainable solution of the problems. These techniques have largely minimized the amount of cutting fluids used in machining while providing similar or even better cutting performances compared to wet cooling methods.

Debnath *et al.* [21] have studied the effect of various cutting fluid levels and cutting parameters on surface roughness and tool wear. They have carried out an experiment on mild steel bar using a TiCN + Al_2O_3 + TiN coated carbide tool insert in the CNC turning process using Taguchi orthogonal array.

Chinchanikar *et al.* [22] have discussed about the comparative evaluations of surface roughness during turning with water based cutting fluid and vegetable oil based cutting fluid.

Agrawala *et al.* [23] have investigated about the experimental investigation into wear characteristics of M2 HSS tool using cotton seed oil. Further an attempt was taken to identify the influence of cotton seed oil in reducing the wear and frictional force. The performance of cotton seed oil has been also compared with the wet conditions by using SAE 40 oil.

Lawal *et al.* [24] have suggested about the advantages of cutting fluids and its performances with respect to the cutting force, surface finish of work piece, tool wear and temperature at the cutting zone. In this paper, the applicability of vegetable oil-based metal cutting fluids in machining of ferrous metals has been discussed. The environmental and health impacts of industrial activities in the society are forcing to reduce the use of mineral oil-based cutting fluid and as a result investigations are being made with reduction of use in mineral oil based cutting fluid.

Deiaba *et al.* [25] have investigated about the analyzing of lubrication strategies for sustainable machining during turning of titanium alloy. The key area of this paper was the search for environmentally benign cooling strategies. Technique likes dry and cryogenic machining, minimum quantity lubrication, minimum quantity cooled lubrication have also been proposed. Here vegetable oils have been proposed as sustainable alternatives to the conventional synthetic emulsion coolants.

Lawal *et al.* [26] have highlighted the performance and drawback of each (dry and MQL) technique based on the machining parameter. They have concluded by making a case study for minimum quantity lubrication (MQL) method using vegetable oil-based lubricant in different machining processes, as a way of addressing the environmental health issues and cost associated with the application of lubricant in machining processes.

Xavior and Adithan [27] have indicated the influence of cutting fluids on tool wear and surface roughness during the turning of austenitic stainless steel with carbide tool. The results have indicated that the cutting fluid has some considerable influence on both surface roughness and tool wear.

Lawal *et al.* [28] have made some work on the evaluation of vegetable and mineral oil in water emulsion cutting fluids, in turning operation with coated carbide tool, using Taguchi methodology and compared with the conventional oil-in-water emulsion cutting fluid. Palm kernel and cotton seed oils have been selected for the formation of oil-in-water emulsion, which are not dangerous to the environment.

Cetin *et al.* [29] have described about the evaluation of vegetable based cutting fluids with extreme pressure and cutting parameters in turning operation by Taguchi method. Here performances of four different vegetable oil based cutting fluids and two commercial types of cutting fluids have been evaluated for reducing of surface roughness during turning of AISI 304L austenitic stainless steel with carbide insert tool.

Ozcelik *et al.* [30] have indicated about the experimental studies on the performances of vegetable based cutting fluids with extreme pressure in turning operations. The performances of these cutting fluids have been compared with respect to surface roughness, cutting and feed forces and tool wear during longitudinal turning of AISI 304L.

Shashidhara & Jayaram [31] have studied about the vegetable oils as cutting fluids in the manufacturing sector, particularly, metal cutting and metal forming. Due to their environmental friendly characteristics, these cutting fluids have been utilized to develop biodegradable lubricants for various industrial applications. The trend was extended to formulate environmental friendly metal cutting fluids. In this paper, the authors have discussed in two approaches, one based on the desirable properties of vegetable oil as metal working fluid and other on the performance of these oils for various cutting and forming operations.

Shalaby *et al.* [32] have presented the performance of three different cutting tool materials, namely: PCBN, TiN coated PCBN, and mixed aluminum ceramic (Al2O3þTiC) in the turning of medium hardened D2 tool steel (52 HRC).

Lotfi *et al.* [33] have developed an accurate 3D finite element model to predict the tool wear of PVD-TiAlN coated carbide and ceramic inserts in turning of Inconel 625.

Suresh and Basavarajappa [34] have developed a response surface methodology as a function of cutting parameters in turning of hardened AISI H13 steel (55 HRC) with PVD coated (Ti-CN) ceramic tool under dry cutting condition. The mathematical models correlating the machining parameters with tool wear and surface roughness has been established. Design of experiment has been employed based on the central composite design concept of response surface methodology.

Haddag *et al.* [35] have analyzed tribological behavior and tool wear mechanisms in rough turning of 18MND5 steel using coated grooved insert, the steel used for steam generators of nuclear power plants. A numerical model has been developed to predict finely the tool wear as revealed by experimental observations.

More *et al.* [36] have investigated of cBN plus TiN (cBN–TiN) composite-coated, commercial grade, carbide inserts (CNMA 432, WC–Co (6% Co)) for hard turning applications in an effort to address these concerns. The effect of cutting speed and feed rate on tool wear (tool life), surface roughness and cutting forces of the cBN–TiN coated carbide inserts have been experimented and analyzed using analysis of variance (ANOVA) technique, and the cutting conditions for their maximum tool life have been evaluated. The tool wear, surface roughness and cutting forces of the cBN–TiN coated and commercially available PCBN tipped inserts have been compared under similar cutting conditions. Both flank wear and crater wear have been observed.

Ayed *et al.* [37] have investigated the machinability of the titanium alloy Ti17 with and without high-pressure water jet assistance (HPWJA) using uncoated WC/Co tools. They have also investigated tool wear and cutting forces varying cutting speed and the water jet pressure. The cutting speed has been varied between 50 m/min and 100 m/min and the water jet pressure has been varied from 50 bar to 250 bar.

Sahu & Choudhury [38] have studied the performance of multi-layer TiN coated tool in machining of hardened steel (AISI 4340 steel) under high speed turning, which has also been compared with that of uncoated tool. The influences of cutting parameters (speed, feed and depth of cut) on surface roughness have been analyzed using Taguchi methodology. They have used scanning electron microscopy (SEM) images to observe the surface morphology and to predict the tool wear.

Sayuti *et al.* [39] have investigated the use mist of SiO_2 nano-lubricant in MQL cooling in hard turning process of hardened steel AISI4140 by conducting analysis on tool wear and surface roughness using fuzzy logic and response analysis to determine statistically significant process parameters.

Zhuang *et al.* [40] have experimented the wear mechanism of alumina-based ceramic cutting tools during dry turning of Inconel 718. Base on observation result of tool wear, a predictive model has been developed of tool wear depth considering the influence of work hardened layer. Then series of cutting tests have been performed to validate the proposed wear model.

Roy [41] have carried out a machining performance test of mustard oil and Servocut 51 in plain turning of C40 bar using uncoated carbide insert at different speed, feed and constant depth of cut. Servocut 51, mustard oil have been used in flood cooling, MQL respectively. They have developed gravity feed MQL system.

Misra [42] have investigated on vegetable oil such as sunflower oil, mustard oil and soyabean oil in plain turning of steel bar using HSS tool at different cutting speed, feed and depth of cut. He has utilized RSM technique on this machining process and perform conformity test.

Also some textbooks and websites [43-50] have also been consulted for collecting information about tool material, tool geometry, tool wear, surface roughness and cutting fluid application in connection with the present work.

1.10 Objective of the present study

Within the scope of the above literature review it is clear that a lot of research work have been carried out on effects of cutting fluid and MQL in turning process. The cutting fluids were conventional and also bio degradable vegetable oil. In view of the reported beneficial aspects of bio degradable vegetable oil and minimum quantity lubrication (MQL) in machining applications, the present investigation aims to explore the potential of commercially available soyabean oil as cutting fluid in MQL machining using mist cooling method by evaluating machining performance in terms of tool wear and generated surface roughness in straight turning of AISI 1055 steel by coated carbide insert at different cutting parameters. Also the results of machining under MQL have been compared with those with those of dry cutting and wet cutting.

CHAPTER 2

MQL SET-UP DEVELOPMENT

2.1 Minimum Quantity Lubrication (MQL):

Minimum Quantity Lubrication (MQL) is the process of applying small amounts of lubricant directly to the cutting tool/work piece interface instead of using traditional flood cooling. MQL minimizes environmental impact by significantly reducing fluid usage and eliminating the need for coolant treatment and disposal. The concept of MQL has been suggested a decade ago as a mean for addressing the issues of environmental intrusiveness and occupational hazard associated with cutting fluid particles. The minimization of cutting fluid leads to economical benefits by saving lubricant costs. Workpiece, tool and machine cleaning time are reduced. The MQL technique consists of misting or atomizing a very small quantity of lubricant, typically of a flow rate of 50 to 500 ml/hour, in an air flow directed towards the cutting zone. The lubricant is sprayed by means of an external supply system consisting of one or more nozzles. The amount of coolant used in MQL is about very low in magnitude compare to the amount commonly used in flood cooling condition. MQL, also known as “Microlubrication” and “Near-Dry Machining”, is the latest technique of delivering metal cutting fluid to the tool/work interface. For the present work the MQL set-up is planned and developed, and discussed in the following sub-section.

2.2 MQL set-up development:

A setup of highly compressed MQL system of laboratory scale has been developed for this investigation, which is shown in Fig 2.1. In this arrangement, by electric power supply (1), motor (3) drives the reciprocating compressor (4) and the compressed air is stored in the air tank (2). A pressure gauge (5) is mounted to measure the air pressure and air flow is controlled by a flow control valve (6). The cutting fluid is kept in a container (7). The compressed air is mixed with the cutting fluid in the required proportion in mixing chamber (9) and finally this mixture of air and cutting fluid is sprayed in the cutting zone by the nozzle (8).

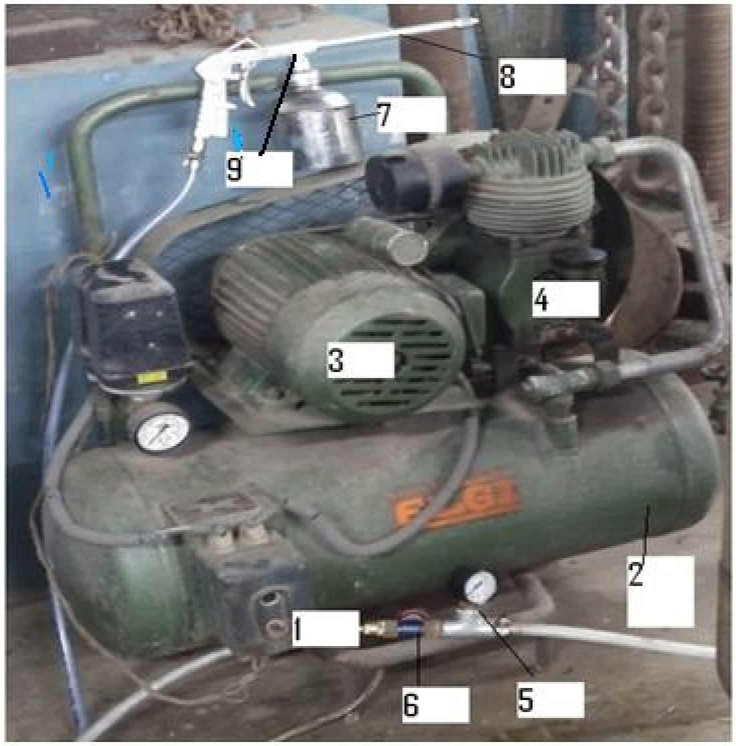


Fig 2.1. Photographic view of laboratory scale MQL system

The detail of the mixing chamber is shown in Fig 2.2. A spray gun has been used for this purpose. In this figure at the position of '3', the fluid container is held in position by threaded element. The opening '1' of the tube 'P1' is blocked. The fluid may be allowed to come out from the container through the opening '1', but in that case it is observed that the amount of fluid is too high and wastage of fluid takes place. To overcome that difficulty, a very small hole at position '2', on the tube 'p1' is made by a needle and the opening at '1' is blocked. The cutting fluid under pressure is allowed to pass through this port opening '2' and is allowed to pass to pipe 'P1'. When the lever '4' is pressed, fluid comes out from the container through 'P1' and mixes with the compressed air, supplied through opening '5' from air tank. The air-fluid mixture is obtained and moves in the direction shown in the figure. A better control of the flow rate is thus obtained. The flow rate with this could be controlled up to 90 ml/hr.

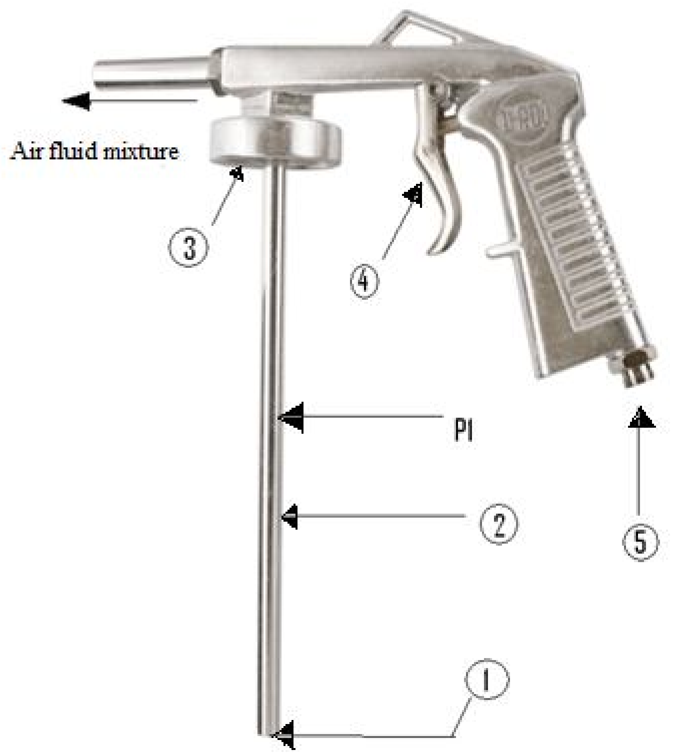


Fig 2.2 View of the mixing chamber

The compressed air is supplied using reciprocating type air compressor and the air pressure is adjusted to 5 bar pressure using the pressure regulator which is kept constant throughout the experiment. Air is then allowed to flow through 12 mm compressor pipe line and this pipe is connected to mixing chamber (spray gun). At the other end of the spray gun a 12 mm metal pipe has been used and the tip of this tube is so modified that it acts as a converging nozzle. By trial and error method the flow rate is so adjusted to deliver the desired flow rate (90 ml/hr) at specific angle of setting of the attachment.

CHAPTER 3

EXPERIMENTAL SET UP AND PROCEDURE

The objective of the present work has been stated in the previous chapter. The experimental plan, experimental set up and experimental procedure are being presented in this chapter. The present study has been done through following plan of experiment:

- Necessary step has been taken to make the lathe ready for machining operation.
- Development and preparation of the MQL set-up.
- The job selected for this experiment is cylindrical AISI 1055 steel and is held between two centers.
- Cutting tool is SNMG 120408 coated carbide tipped tool and the tool tip is fixed on the tool holder.
- Three types of cutting condition are selected- dry, wet and MQL.
- The metal cutting operation has been performed with constant feed, and different depth of cut and job rpm.
- The chips have been collected for visual observation.
- Surface roughness and tools wear have been measured with the help of a Portable Surface Roughness Tester and Optical Microscope.
- Taper turning test has been done to find exponent of Taylor's tool life equation under each cutting condition.
- After getting the experimental results, the result has been analyzed and the tool life has been predicted for each case.

3.1 General description of the experiment:

Operation: Plain turning

Machine tool: Centre Lathe, 10 hp

Job material: AISI 1055 steel

Job length: 600 mm

Initial job diameter: 70 mm

Effective cutting length: 280 mm

Cutting insert type: Coated carbide inserts

Cutting insert configuration: ISO SNMG120408

Spindle speed: 620 rpm and 800 rpm

Feed: 0.08   mm

Depth of Cut: 1.0 mm & 1.2 mm

Cutting fluid: Vegetable oil (soya been oil)

Environment: Dry (no cutting fluid), Wet (soya bean oil is used as cutting fluid with flow rate of 10 l/hr), MQL

Time of each cutting: 5 min.

The machining operations have performed under following conditions given in Table 2.1. For each combination of spindle speed, feed and depth of cut, the tool has been travelled through the required length for five passes of duration of five minute each.

Table 3.1. Combination of cutting parameters

Sl. No.	Cutting condition	Spindle speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1.	Dry	620	0.08	1.0
2.	Dry	800	0.08	1.0
3.	Dry	620	0.08	1.2
4.	Dry	800	0.08	1.2
5.	Wet	620	0.08	1.0
6.	Wet	800	0.08	1.0
7.	Wet	620	0.08	1.2
8.	Wet	800	0.08	1.2
9.	MQL	620	0.08	1.0
10.	MQL	800	0.08	1.0
11.	MQL	620	0.08	1.2
12.	MQL	800	0.08	1.2

3.2 Experimental procedure

Machining performance depends on type of cutting tool insert used as well as on its geometry and cutting edge condition, machine tool used and on the process parameters employed. The machining environment however depends on whether metal cutting fluid is being used. Here experiment are done under three cutting condition

- DRY
- WET
- MQL

3.3 Equipment used

The equipments used are being discussed.

3.3.1 Machine tool used

Lathe is used in this work. Photographic view of the lathe is shown in Fig 3.1.

Fig 3.1. Photographic view of the lathe

The specification of the lathe is given below:

- Make- American Pacemaker
- Spindle speed range-13 to 800 rpm

- Feed range -0.0033 to 0.2 inch/rev
- Power-10 hp
- Lathe bed length- 5.1 meter

3.3.2 Cutting Tool used

In this investigation Coated carbide inserts have been selected as cutting tool inserts because of its optimum combination of properties at high speed turning. These insert have configuration of SNMG 120408 with CVD coating and coating layer is TiCN- Al_2O_3-TiN. The top coating of TiN decreases a friction coefficient between the chip and the tool. Al_2O_3 coating in the middle layer is for adhesion resistance while TiCN is coating for abrasion resistance. Cutting insert of the present work is shown in the Fig 3.2.

The details of ISO SNMG 120408 inserts are:

S- Insert shape (90^0 square)

N- Clearance angle (0^0)

M- Medium tolerance (±0.005 inch)

G- Built-in chip breaker with rigid clamping type inserts

12- Length of each cutting edge (12 mm)

04- Thickness of the tool (4 mm)

08- Nose radius (0.08 mm)

Fig 3.2. Photographic view of the cutting tool inserts

3.3.3 Job material

Job material is AISI 1055.

Chemical composition:

Carbon-	0.50%,
Silicon-	0.24%,
Manganese-	0.74%,
Sulphur-	0.028%,
Phosphorus-	0.034%
Iron-	97.54%

Mechanical properties:

Tensile strength-	700 MPa,
Hardness-	201-255 HB

Typical Applications**:**

Sprockets, Cylinders, Cams, Crankshafts, Keys, Small Gears, Machine Tools, Grinding Balls for Ball Mills, Bolts, Nuts, Pulleys

3.3.4 Cutting fluid details

Soya bean oil has been used as the cutting fluid. The properties have been presented as below:

- Viscosity (cS) - 35.4 at 38^{o}C
- Specific gravity – 0.916-0.922
- Iodine value – 128-143
- Freezing point - -18^{o}C
- Smoke point - 238^{o}C
- Specific heat- 1.675 (kJ/kg.K)
- Thermal conductivity - 0.17±0.02 (W/ m.K)

3.3.5 Surface Roughness Tester

To measure the surface roughness a portable surface roughness tester is used. Photographic view of the tester is shown in Fig 3.3 and the specification is given below:

Fig 3.3. Photographic view of portable surface roughness tester

Specification:

- Make- Mitutoyo
- Sl No- 99MBB079A6
- Sampling length (L) – 0.25 mm, 0.8 mm, 2.5 mm,
- Stylus tip radius – 200 µm (5 µm)
- Material of stylus – Diamond
- Weight – 0.5 kg
- Max measurement range – 350 µm (-200 µm to +150 µm)

3.3.6 Optical Microscope

After machining, flank wear may occur on the flank surface and it is to be measured by using optical microscope. Photographic view of the optical microscope is shown in Fig 3.4. By taking image of the principal flank surface, the flank wear have been measured (the maximum value of wear has been considered). The specification of the microscope is given below:

Fig 3.4. Photographic view of optical microscope

Specification:

- Make: Leica.
- Microscope Type: Optical Measuring microscope.
- Microscope Features: Camera, computer interface, digital display, fine focus, image analysis processing software, and mechanical stage.
- Observation Methods: Fluorescence.
- Applications: Metallurgical, semiconductor, MEMS and nanotechnology.
- Eyepiece Styles: Binocular,
- Eyepiece Magnification: 200X
- Illuminator: 20 W halogen.
- Objective Magnification: 50X, 100X, 200X, 400X and 500X.
- Magnification Range: 50X to 500X

The results of the experiment and discussion on results of the same are presented in Chapter-4.

CHAPTER 4

RESULTS & DISCUSSION

The experimental results on the surface roughness and the flank wear in turning operation have been measured. Also the shape and the color of the chip have been noted. They are listed and discussed in this chapter.

4.1 Results

In Table 4.1, the different chip shape and its color under different cutting conditions have been presented.

Table 4.1 Chip shape and color under different cutting conditions

Cutting conditions	Spindle Speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Chip shape	Chip color
Dry	620	0.08	1.0	Helical	Golden
Dry	800	0.08	1.0	Helical	Golden
Dry	620	0.08	1.2	Helical	Golden
Dry	800	0.08	1.2	Helical	Golden
Wet	620	0.08	1.0	Tubular	Silver
Wet	800	0.08	1.0	Tubular	Silver
Wet	620	0.08	1.2	Tubular	Silver
Wet	800	0.08	1.2	Tubular	Silver
MQL	620	0.08	1.0	Tubular	Silver
MQL	800	0.08	1.0	Tubular	Silver
MQL	620	0.08	1.2	Helical	Silver
MQL	800	0.08	1.2	Helical	Silver

The experimental results of surface roughness (µm) are given in the Table 4.2.

Table 4.2 value of surface roughness (R_a) under different cutting conditions

Cutting conditions	Spindle Speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Average surface roughness (R_a) µm				
				5 min	10 min	15 min	20 min	25 min
Dry	620	0.08	1.0	1.12	1.42	1.61	2.75	2.81
Dry	800	0.08	1.0	1.12	1.24	1.44	2.64	2.67
Dry	620	0.08	1.2	1.16	1.24	1.96	2.71	2.80
Dry	800	0.08	1.2	1.18	1.34	1.74	2.45	2.65
Wet	620	0.08	1.0	1.44	1.51	1.76	2.07	2.57
Wet	800	0.08	1.0	1.43	1.45	1.56	1.85	2.31
Wet	620	0.08	1.2	1.50	1.63	1.68	2.06	2.62
Wet	800	0.08	1.2	1.41	1.51	1.68	1.98	2.40
MQL	620	0.08	1.0	0.79	0.91	1.58	1.77	2.42
MQL	800	0.08	1.0	0.96	1.16	1.40	1.70	2.30
MQL	620	0.08	1.2	1.00	1.26	1.61	2.22	2.47
MQL	800	0.08	1.2	1.41	1.51	1.68	1.98	2.40

The experimental results of flank tool wear (μm) are shown in the Table 4.3.

Table 4.3 Value of flank wear (V_B) under different cutting conditions

Cutting conditions	Spindle Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Flank wear (V_B) μm				
				5 min	10 min	15 min	20 min	25 min
Dry	620	0.08	1.0	52.30	71.28	79.70	91.50	105.20
Dry	800	0.08	1.0	55.40	82.28	91.70	100.50	118.50
Dry	620	0.08	1.2	53.50	78.78	84.40	102.50	108.20
Dry	800	0.08	1.2	60.50	85.00	104.50	120.60	132.50
Wet	620	0.08	1.0	46.00	73.00	76.60	89.00	100.40
Wet	800	0.08	1.0	48.70	81.35	89.50	103.50	109.60
Wet	620	0.08	1.2	46.60	75.00	83.42	92.70	105.10
Wet	800	0.08	1.2	55.90	88.00	96.50	108.20	114.90
MQL	620	0.08	1.0	45.00	68.54	79.70	90.60	96.80
MQL	800	0.08	1.0	48.10	75.25	85.00	94.20	100.90
MQL	620	0.08	1.2	46.70	67.43	80.20	92.80	97.80
MQL	800	0.08	1.2	54.40	78.00	93.20	96.35	110.20

4.2 Discussion

The discussion on chip characteristics, surface roughness and tool wear and related graphical plots under three cutting condition are presented in the following sub sections.

4.2.1 Discussion on chip characteristics, surface roughness and tool wear under Dry cutting

- **Chip characteristics**

In Dry cutting, generally chips shapes are helical type in all the cutting conditions and chips are golden in color. Some figures of chip in Dry cutting are shown in Fig 4.1(a) to Fig 4.1(d).

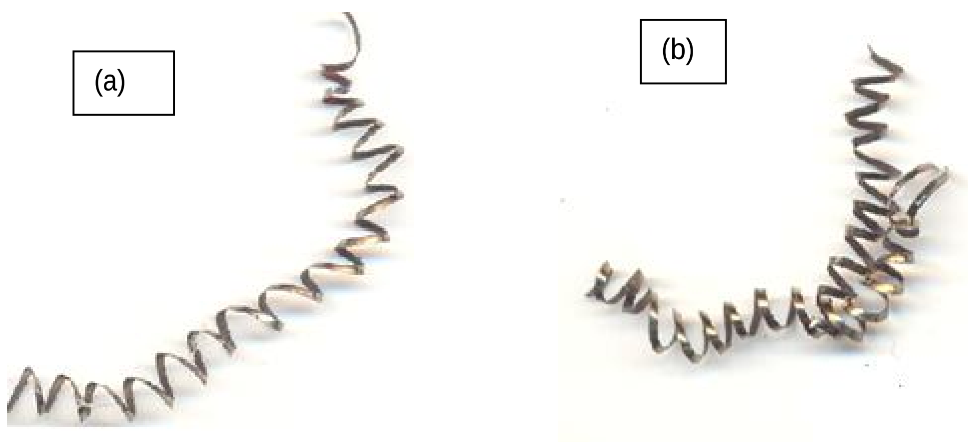


Fig 4.1 (a) Chip shape and color at 620 rpm, 0.08 mm/rev and 1 mm depth of cut and (b) Chip shape and color at 800 rpm, 0.08 mm/rev and 1 mm depth of cut

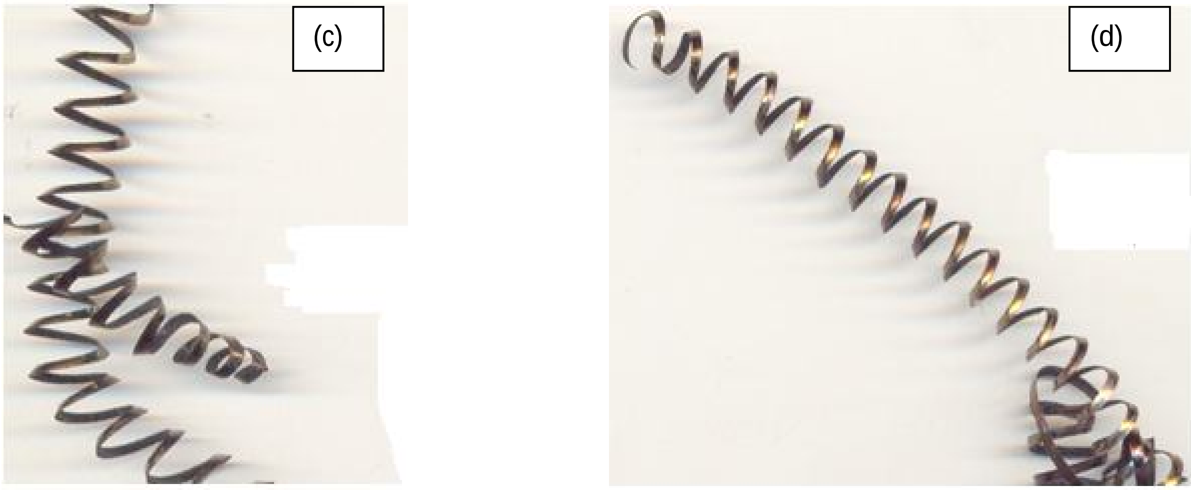


Fig 4.1 (c) Chip shape and color at 620 rpm, 0.08 mm/rev and 1.2 mm depth of cut and (d) Chip shape and color at 800 rpm, 0.08 mm/rev and 1.2 mm depth of cut

Helical chip shape with golden color has been obtained in dry cutting whereas tubular shape with silver color has been obtained in case of machining in wet condition and MQL environment. It is in well agreement with the work of Khan et al. [4].

- **Surface roughness**

In case of dry cutting at different cutting conditions, variations of surface roughness with time are shown in Fig. 4.1(e) to Fig. 4.1 (h) .

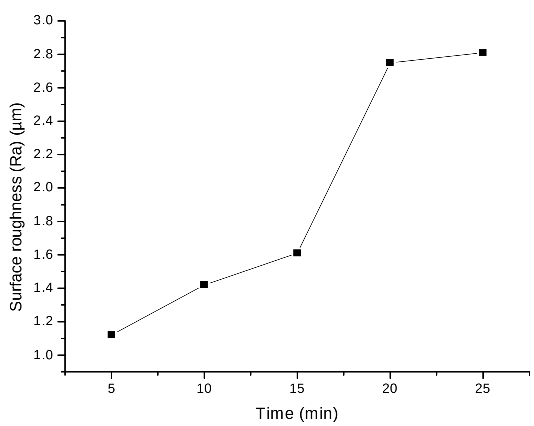


Fig 4.1(e) Variation of surface roughness at spindle speed 620 rpm, Feed 0.08 mm/rev and depth of cut 1.0 mm

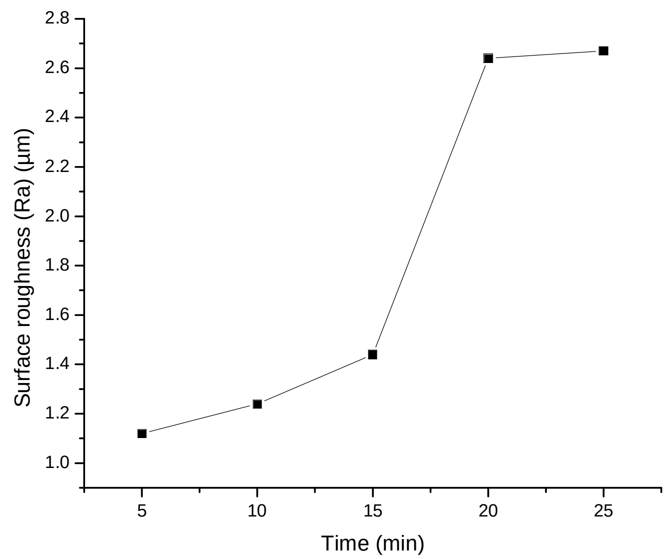


Fig 4.1(f) Variation of surface roughness at spindle speed 800 rpm, Feed 0.08 mm/rev and depth of cut 1.0 mm

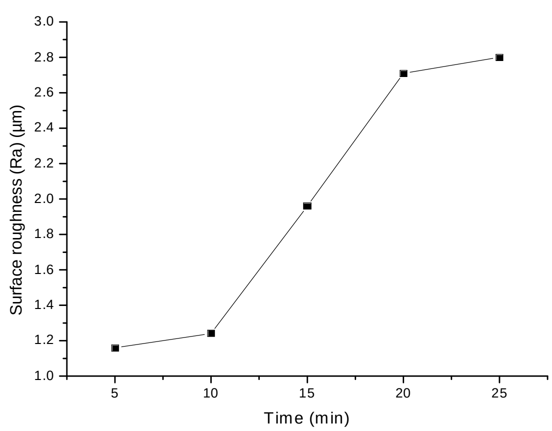


Fig 4.1(g) Variation of surface roughness at spindle speed 620 rpm, Feed 0.08 mm/rev and depth of cut 1.2 mm

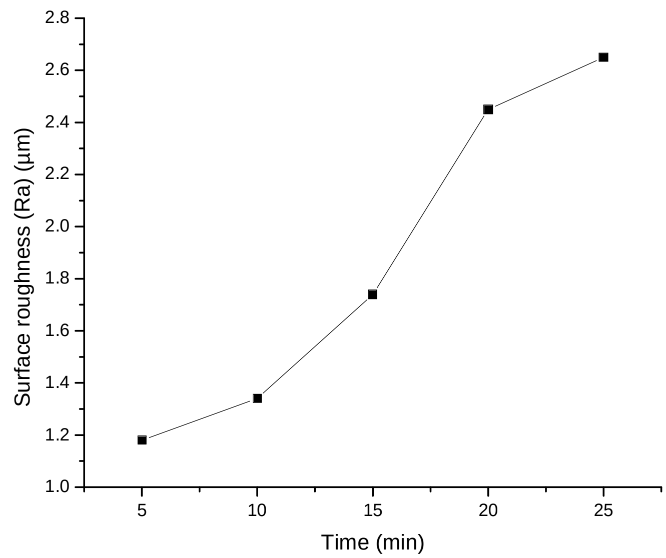


Fig 4.1(h) Variation of surface roughness at spindle speed 800 rpm, Feed 0.08 mm/rev and depth of cut 1.2 mm

In the above figures it is seen that there is a consistent trend of increase in R_a value with increase in time. This may be due to the fact that as the time increase the flank wear increases and as a result the flank angle changes (decreases). This increases the rubbing action between the machined surface and flank surface of the tool and the surface finish deteriorates.

By keeping the spindle speed constant at 620 rpm and feed at 0.08 mm/rev for two different depths of cuts of 1 mm and 1.2 mm respectively the variation of surface roughness against time has been plotted in Fig. 4.1(i). It is seen that in both cases the surface roughness value increases with time due to change in flank angle. But the change of depth of cut does not significantly contribute to the change in the surface roughness value.

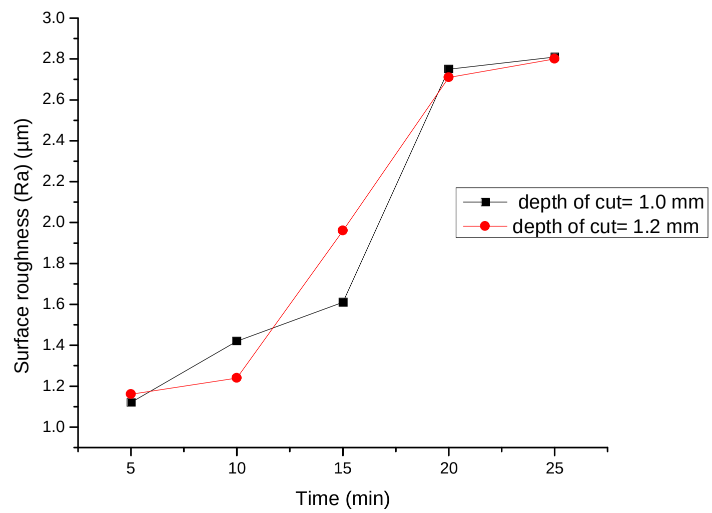


Fig 4.1(i) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 620 rpm and feed 0.08 mm/rev)

Now spindle speed is kept constant at 800 rpm and feed is 0.08 mm/rev, the variation of surface roughness with time for depth of cut 1.0 mm and 1.2 mm respectively is shown in Fig. 4.1(j). In this figure the depth of cut shows a little effect and with higher depth of cut surface finish is not so good as compared to lower depth of cut.

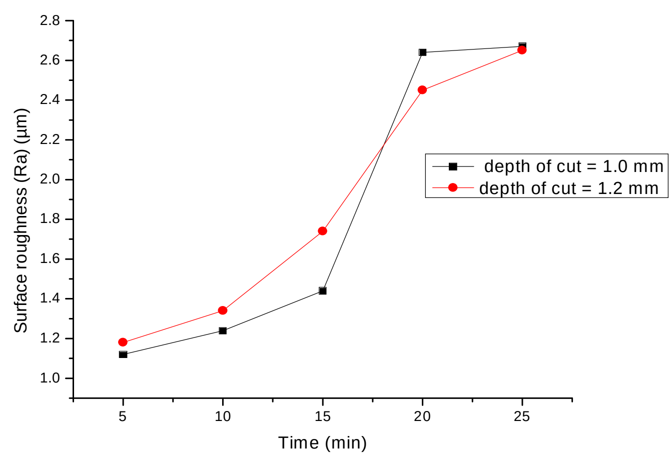


Fig. 4.1(j) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 800 rpm and feed 0.08 mm/rev)

By keeping the depth of cut constant at 1.0 mm and feed at 0.08 mm/rev for two spindle speed of 620 rpm and 800 rpm respectively the variation of surface roughness against time has been shown in Fig 4.1(k). It is seen that in both cases the surface roughness value increases with time due to change in flank angle. Spindle speed has the significant effect on the surface finish. It can be concluded from the plot that with increase of spindle speed surface finish improves.

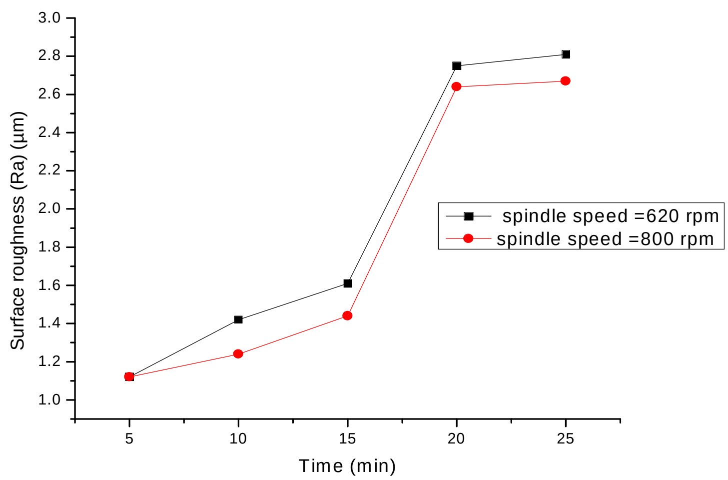


Fig. 4.1(k) Variation of surface roughness value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.0 mm and feed 0.08 mm/rev)

Now spindle speeds have been selected 620 rpm and 800 rpm, feed is kept constant at 0.08 mm/rev and depth of cut at 1.2 mm. The Fig. 4.1(l) shows the variation of surface roughness with time. It is found that the better surface finish has been obtained for spindle speed of 800 rpm and depth of cut at 1.2 mm than the parameter setting of spindle speed of 620 rpm and depth of cut at 1.2 mm.

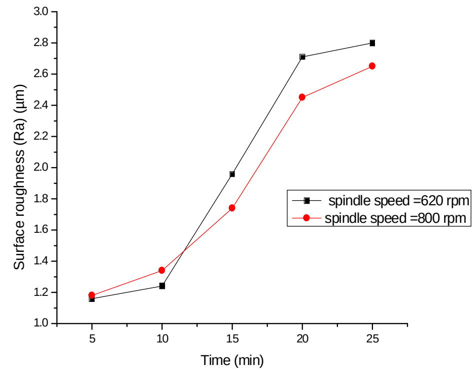


Fig. 4.1(l) Variation of surface roughness value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.2 mm and feed 0.08 mm/rev)

Fig. 4.1(m) shows the variation of surface finish with time at four different cutting conditions keeping feed rate at 0.08mm/rev. It is found that with increases in time surface roughness is increases because it may be flank wear increase for all the cutting conditions. (spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm).

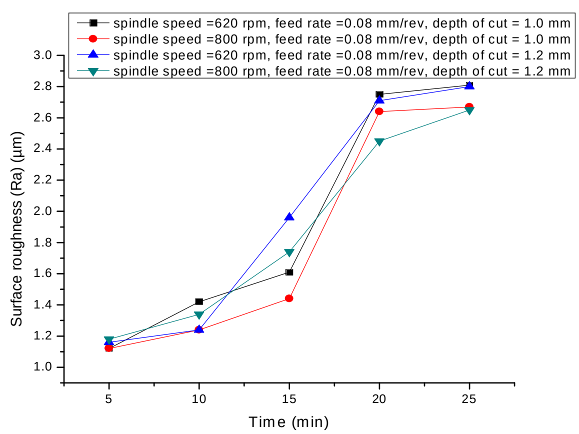


Fig. 4.1(m) Variation of surface roughness value with time for four cutting conditions at spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm

➢ **Flank wear**

In case of dry cutting at different cutting conditions, the variations of flank wear with time are shown in Fig. 4.1(n), Fig. 4.1(p), Fig. 4.1(r) and Fig. 4.1(t). From these plots it is seen after 10 min of cut almost uniform wear is obtained in all the cases. The pictorial views of the flank wear under these conditions (at 200X) have been shown in Fig. 4.1(o), Fig. 4.1(q), Fig. 4.1(s) and Fig. 4.1(u).

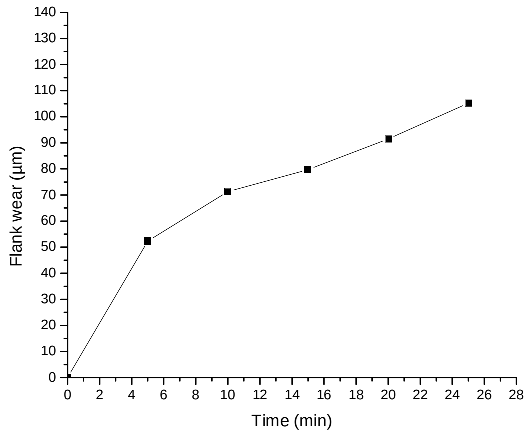


Fig. 4.1(n) variation of flank wear with time at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

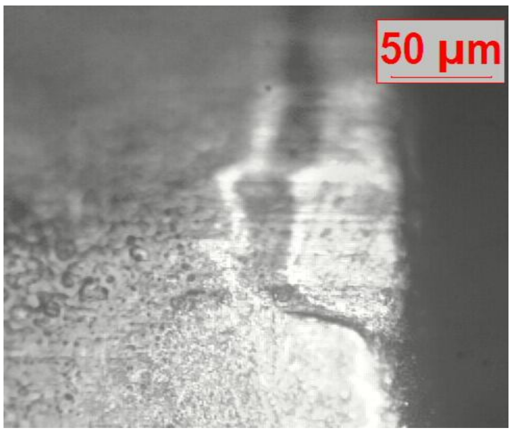


Fig. 4.1(o) Microscopic view of wear at cutting condition of at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

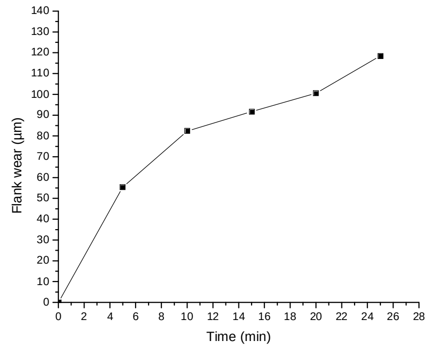


Fig. 4.1(p) variation of flank wear with time at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

Fig. 4.1(q) The microscopic view of wear at cutting condition of at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

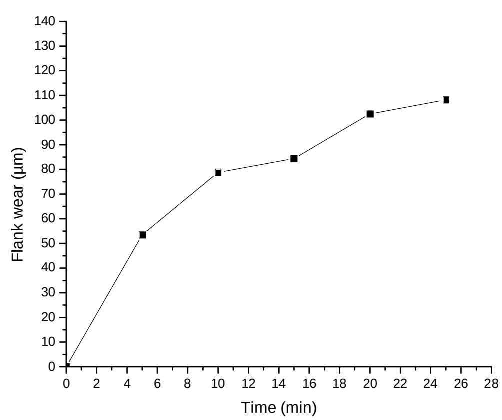


Fig. 4.1(r) variation of flank wear with time at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

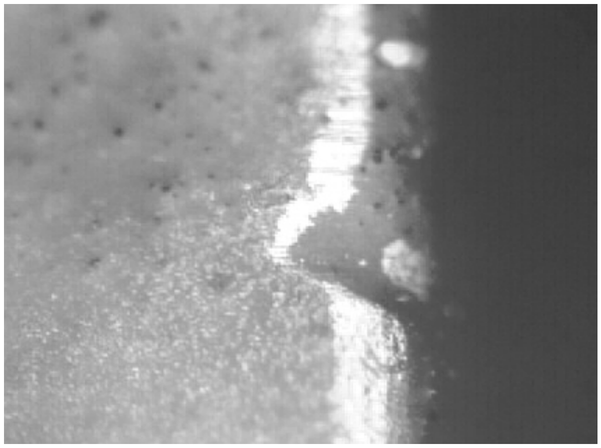


Fig. 4.1(s) The microscopic view of wear at cutting condition of at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

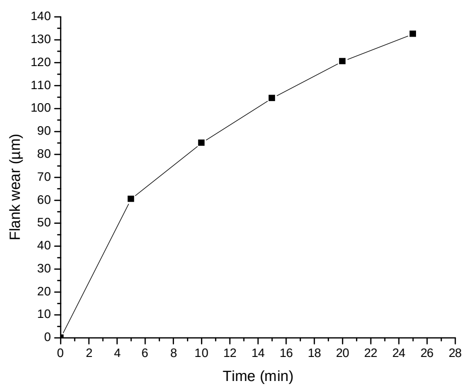


Fig. 4.1(t) variation of flank wear with time at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

Fig. 4.1(u) The microscopic view of wear at cutting condition of at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

Now spindle speed is kept constant at 800 rpm and feed is 0.08 mm/rev, the variation of flank wear with time for depth of cut 1.0 mm and 1.2 mm respectively is shown in Fig. 4.1(v). In this figure the depth of cut shows an effect on tool flank wear.

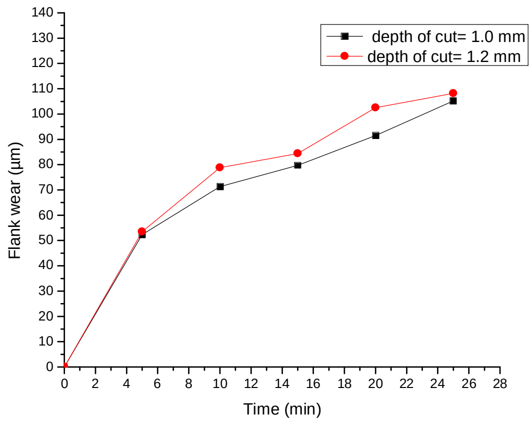


Fig. 4.1(v) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 620 rpm and feed 0.08 mm/rev)

By keeping the spindle speed constant at 800 rpm and feed at 0.08 mm/rev for two different depths of cuts of 1 mm and 1.2 mm respectively the variation of surface roughness against time has been plotted in Fig 4.1(w). It is seen that in both cases the flank wear value increases with time due to the effect of abrasion.

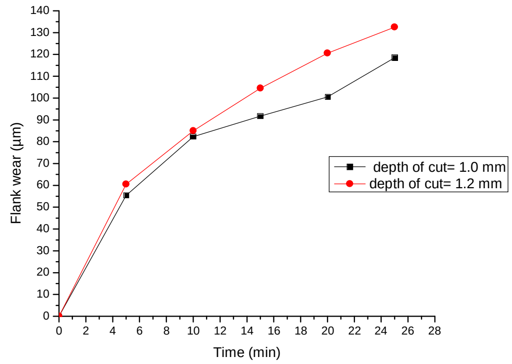


Fig. 4.1(w) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 800 rpm and feed 0.08 mm/rev)

Now spindle speeds have been selected 620 rpm and 800 rpm, feed is kept constant at 0.08 mm/rev and depth of cut at 1.0 mm. The variation of Flank wear with time is shown in Fig. 4.2(x). It has been observed that the flank wear at spindle speed 800 rpm is more as compared to spindle speed of 620 rpm. It is due to much rubbing action takes place at higher spindle speed.

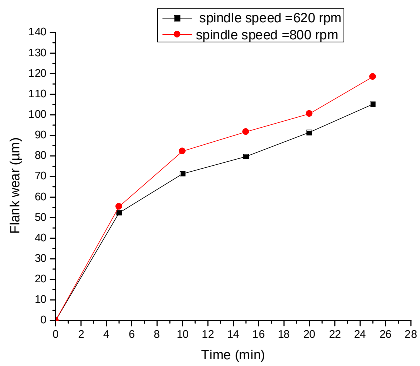


Fig. 4.1(x) Variation of flank wear value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.0 mm and feed 0.08 mm/rev)

By keeping the feed rate constant at 0.08 mm/rev and depth of cut at 1.2 mm for two spindle speed of 620 rpm and 800 rpm respectively, the variation of flank wear against time has been shown in Fig. 4.1(y). It is seen that in the flank wear value at spindle speed 800 rpm is more increasing in nature compare with spindle speed 620 rpm. It can be concluded from the plot that with increase in spindle speed flank wear has been decreased.

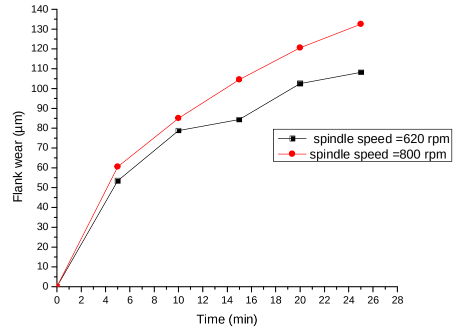


Fig. 4.1(y) Variation of flank wear value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.2 mm and feed 0.08 mm/rev)

Fig. 4.1(z) shows the variation of flank wear with time at four different cutting conditions keeping feed rate constant at 0.08mm/rev. It is found that with increases in time flank wear is increases for all the cutting conditions (spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm) due to abrasion action. The wear rate is very high at cutting condition of spindle speed 800 rpm and depth of cut 1.2 mm than cutting condition of spindle speed 620 rpm and depth of cut 1.0 mm. It can be concluded from the flank wear graph that combination of spindle speed and depth of cut have significant effect in tool wear.

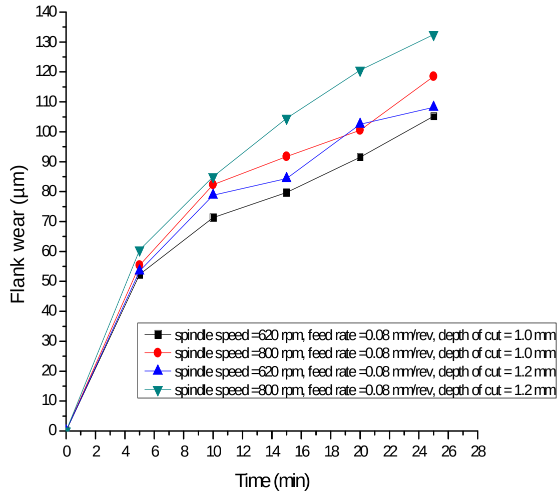


Fig. 4.1(z) Variation of surface roughness value with time for four cutting conditions at spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm

4.2.2 Discussion on chip characteristics, surface roughness and tool wear under Wet cutting

➢ **Chip characteristics**

In case of wet cutting, generally chip shapes are tubular and helical type in all the cutting conditions and chips are silver in color. Some figures of chip in wet cutting are shown in Fig. 4.2(a) to Fig. 4.2(d).

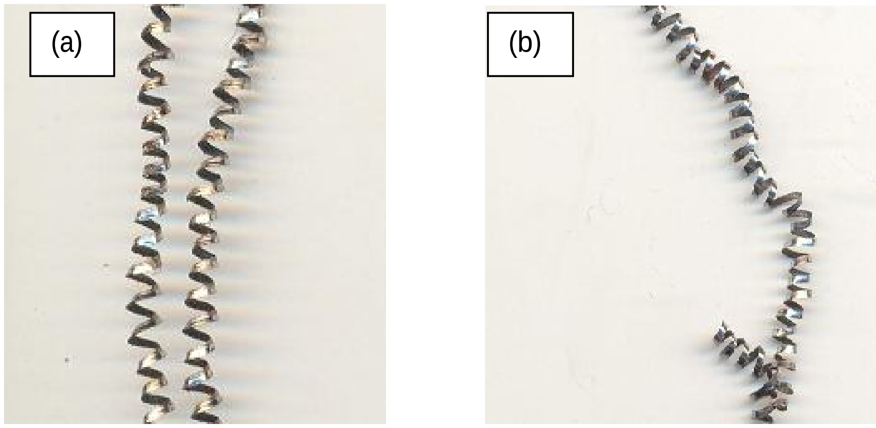


Fig. 4.2(a) Chip shape and color at 620 rpm, 0.08 mm/rev and 1 mm depth of cut and (b) Chip shape and color at 800 rpm, 0.08 mm/rev and 1 mm depth of cut

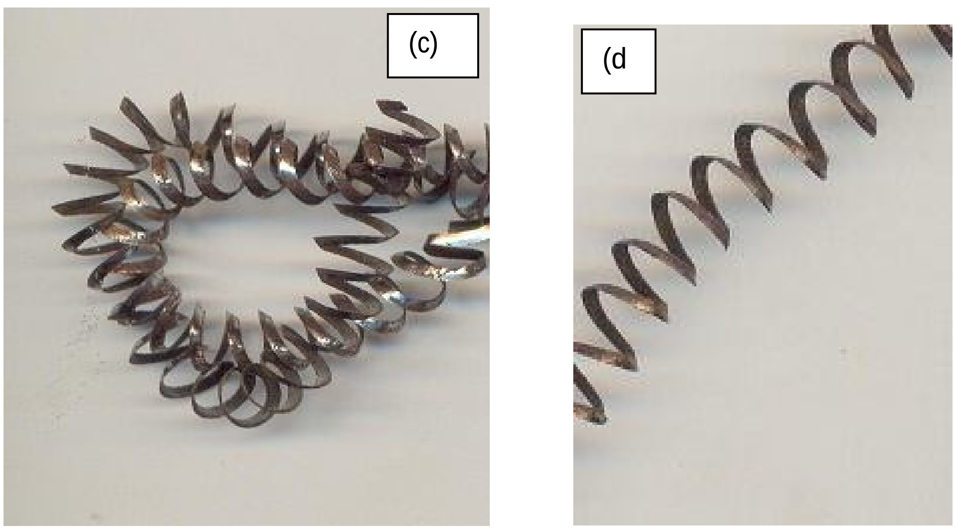


Fig 4.2(c) Chip shape and color at 620 rpm, 0.08 mm/rev and 1.2 mm depth of cut and (d) Chip shape and color at 800 rpm, 0.08 mm/rev and 1.2 mm depth of cut

Helical and tubular chip shape with silver color has been obtained in wet cutting whereas tubular shape with silver color has been obtained in case of machining in MQL condition. But dry cutting helical chip shape with golden color has been noticed. It is in well agreement with the work of Khan et al. [4].

- **Surface roughness**

In case of wet cutting at different cutting conditions, variations of surface roughness with time have been shown in Fig. 4.2(e) to Fig. 4.2 (h).

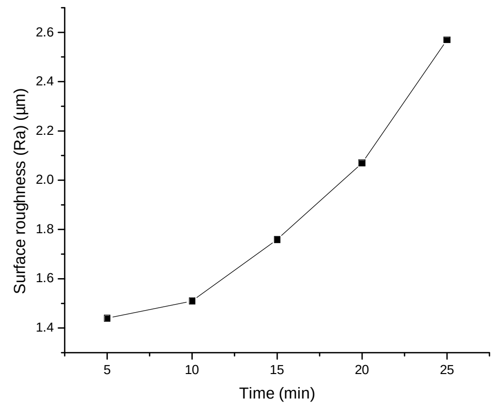


Fig 4.2(e) Variation of surface roughness at spindle speed 620 rpm, Feed 0.08 mm/rev and depth of cut 1.0 mm

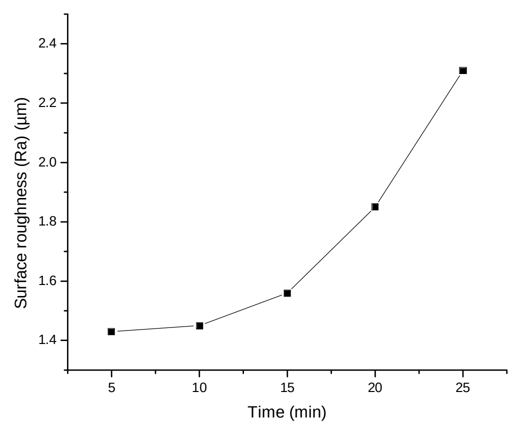


Fig 4.2(f) Variation of surface roughness at spindle speed 800 rpm, Feed 0.08 mm/rev and depth of cut 1.0 mm

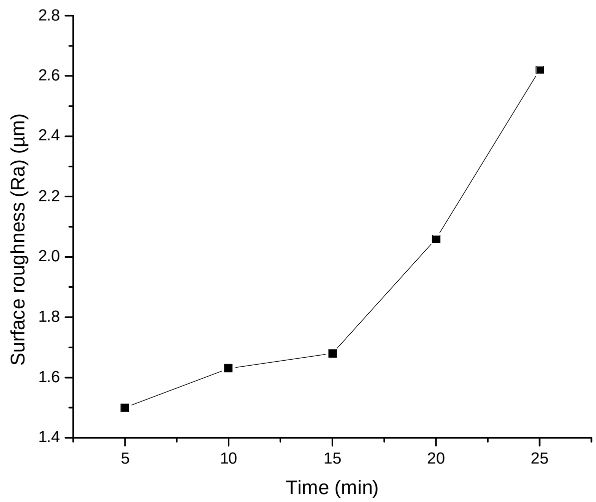


Fig 4.2(g) Variation of surface roughness at spindle speed 620 rpm, Feed 0.08 mm/rev and depth of cut 1.2 mm

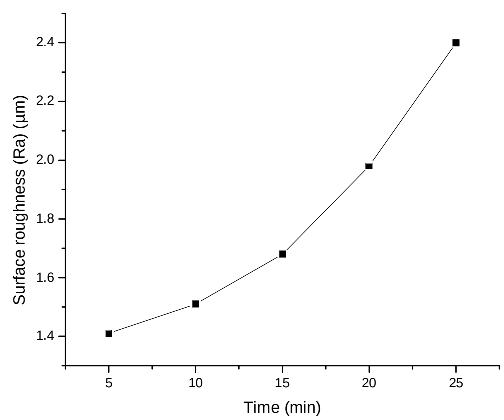


Fig 4.2(h) Variation of surface roughness at spindle speed 800 rpm, Feed 0.08 mm/rev and depth of cut 1.2 mm

In the above figures it is seen that there is a consistent increasing trend of R_a value with time. This may be due to the fact that as the time increase the flank wear increases and as a result the flank angle changes (decreases). This increases the rubbing action between the machined surface and flank surface of the tool and the surface finish deteriorates.

By keeping the spindle speed constant at 620 rpm and feed at 0.08 mm/rev for two different depths of cuts of 1 mm and 1.2 mm respectively the variation of surface roughness against time has been plotted in Fig 4.2(i). It is seen that in both cases the surface roughness value increases with time due to change in flank angle. But the change of depth of cut does not significantly contribute to the change in the surface roughness value.

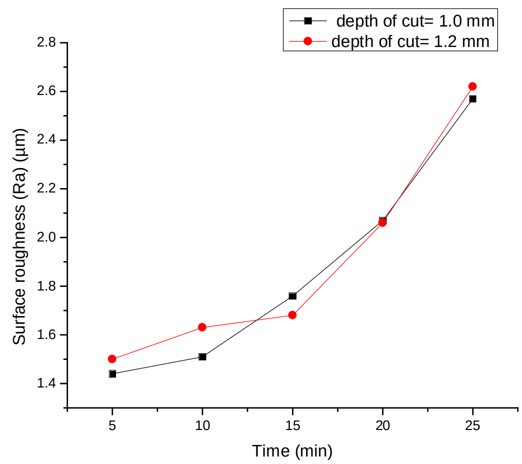


Fig 4.2(i) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 620 rpm and feed 0.08 mm/rev)

Now spindle speed is kept constant at 800 rpm and feed is 0.08 mm/rev, the variation of surface roughness with time for depth of cut 1.0 mm and 1.2 mm respectively is shown in Fig. 4.2(j). In this figure the depth of cut shows a little effect and with higher depth of cut surface finish is more affected as compared to lower depth of cut.

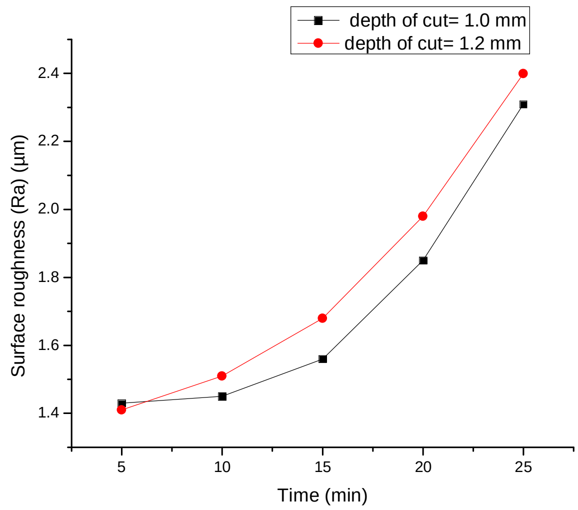


Fig. 4.2(j) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 800 rpm and feed 0.08 mm/rev)

By keeping the depth of cut constant at 1.0 mm and feed at 0.08 mm/rev for two spindle speed of 620 rpm and 800 rpm respectively the variation of surface roughness against time has been shown in Fig 4.2(k). It is seen that in both cases the surface roughness value increases with time due to change in flank angle. Spindle speed has the significant effect on the surface finish. It can be concluded from the plot that with increase of spindle speed surface roughness has been decreased yielding a good surface.

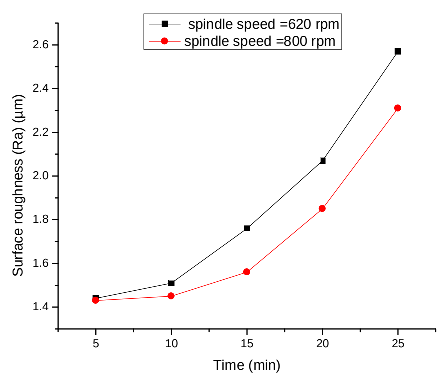


Fig. 4.2(k) Variation of surface roughness value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.0 mm and feed 0.08 mm/rev)

Now spindle speeds have been selected 620 rpm and 800 rpm, feed is kept constant at 0.08 mm/rev and depth of cut at 1.2 mm. The Fig. 4.2(l) shows the variation of surface roughness with time. It is found that the better surface finish has been obtained for spindle speed of 800 rpm and depth of cut at 1.2 mm than the parameter setting of spindle speed of 620 rpm and depth of cut at 1.2 mm.

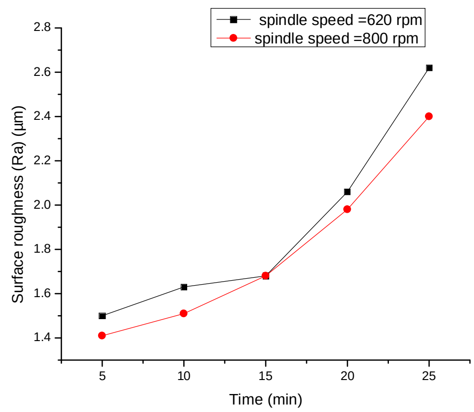


Fig. 4.2(l) Variation of surface roughness value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.2 mm and feed 0.08 mm/rev)

Fig. 4.2(m) shows the variation of surface finish with time at four different cutting conditions keeping feed rate at 0.08mm/rev. It is found that with increases in time surface roughness increases because be flank wear increase for all the cutting conditions. (spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm).

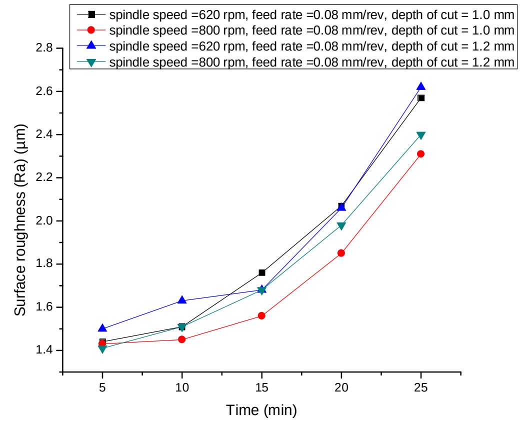


Fig. 4.2(m) Variation of surface roughness value with time for four cutting conditions at spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm

- **Flank wear**

In case of wet cutting for different cutting conditions, the variations of flank wear with time are shown in Fig. 4.2(n), Fig. 4.2(p), Fig. 4.2(r) and Fig. 4.2(t). From these plots an initial break down zone is observed up to 10 min of cut and after that uniform wear zone is obtained. The corresponding views of the flank wear at 200X have been shown in Fig. 4.2(o), Fig. 4.2(q), Fig. 4.2(s) and Fig. 4.2(u).

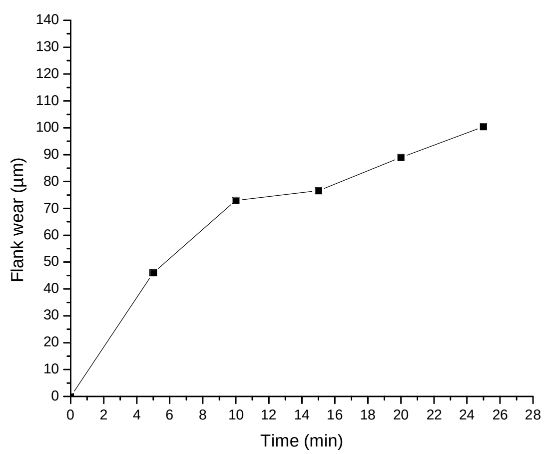


Fig. 4.2(n) variation of flank wear with time at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

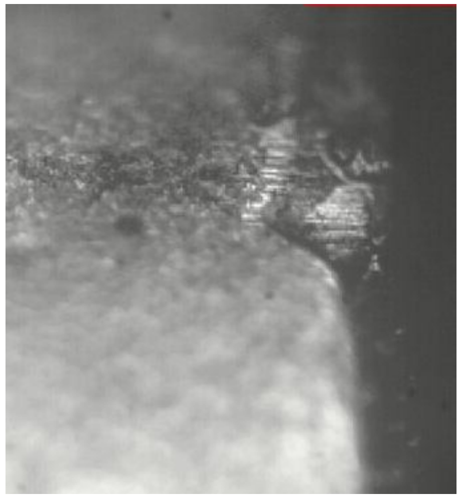


Fig. 4.2(o) The microscopic view of wear at cutting condition of at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

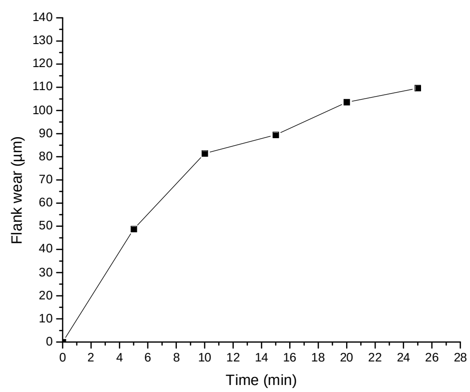


Fig. 4.2(p) variation of flank wear with time at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

Fig. 4.2(q) The microscopic view of wear at cutting condition of at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

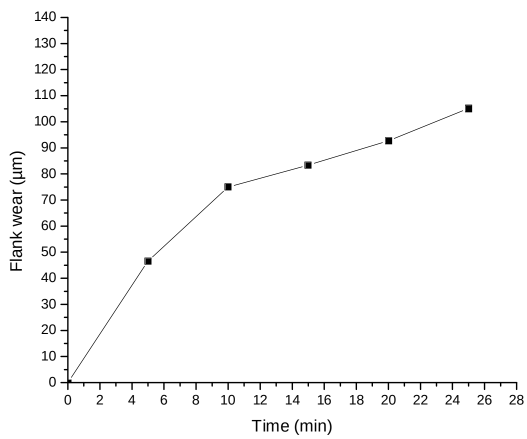


Fig. 4.2(r) variation of flank wear with time at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

Fig. 4.2(s) The microscopic view of wear at cutting condition of at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

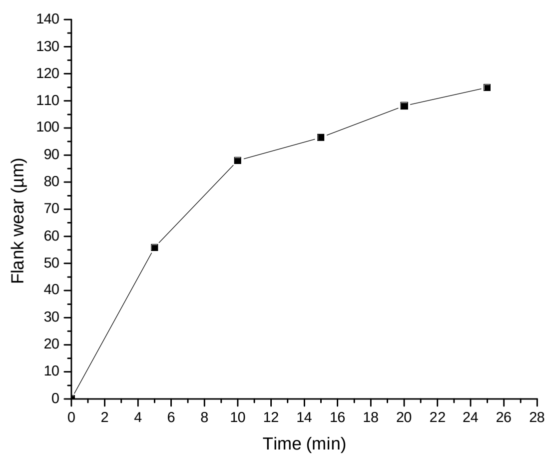


Fig. 4.2(t) variation of flank wear with time at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

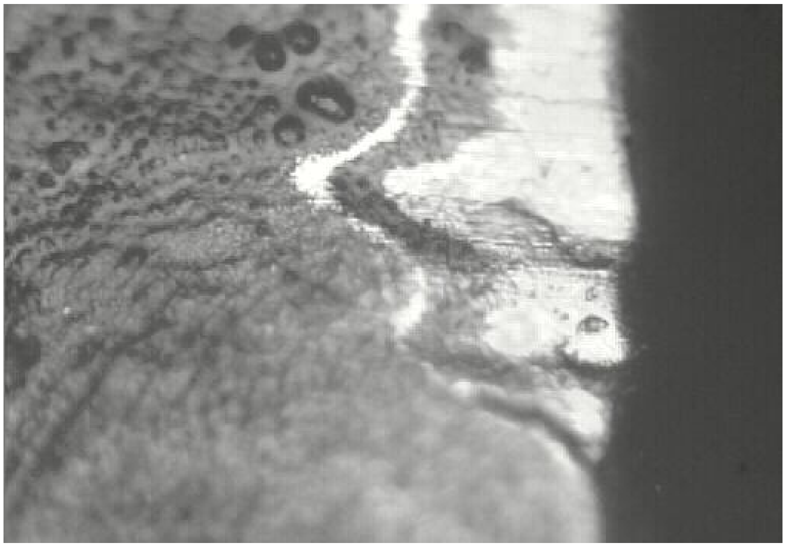


Fig. 4.2(u) The microscopic view of wear at cutting condition of at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

Now spindle speed is kept constant at 800 rpm and feed is 0.08 mm/rev, the variation of flank wear with time for depth of cut 1.0 mm and 1.2 mm respectively is shown in Fig. 4.2(v). In this figure the depth of cut shows a little impact on tool flank wear.

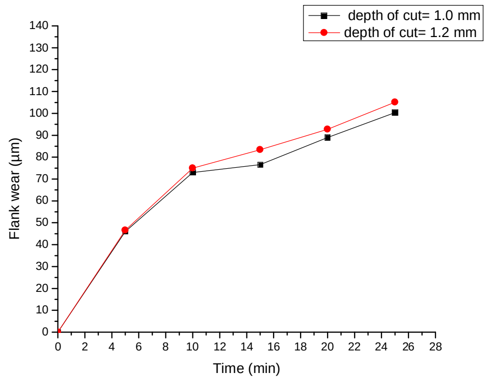


Fig. 4.2(v) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 620 rpm and feed 0.08 mm/rev)

By keeping the spindle speed constant at 800 rpm and feed at 0.08 mm/rev for two different depths of cuts of 1 mm and 1.2 mm respectively the variation of surface roughness against time has been plotted in Fig 4.2(w). It is seen that in both cases the flank wear value increases with time due to abrasion and at the interface of tool and work piece surface. But the change of depth of cut has not much contribution to the change in the Flank wear value.

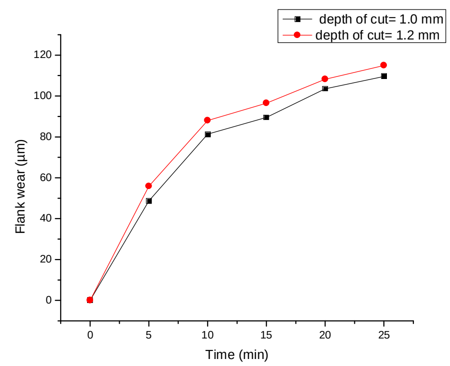


Fig. 4.2(w) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 800 rpm and feed 0.08 mm/rev)

Now spindle speeds have been selected 620 rpm and 800 rpm, feed is kept constant at 0.08 mm/rev and depth of cut at 1.0 mm. The variation of Flank wear with time is shown in Fig. 4.2(x). It has been observed that the flank wear at spindle speed 800 rpm is more as compare to spindle speed of 620 rpm. It is due to much rubbing action takes place at higher spindle speed.

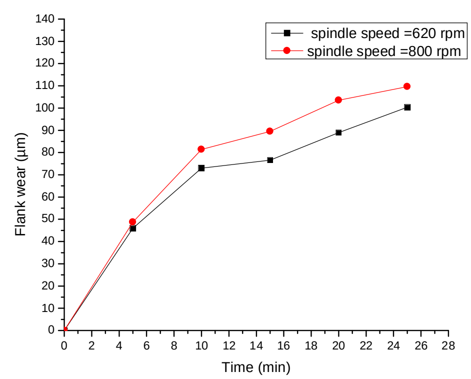


Fig. 4.2(x) Variation of flank wears value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.0 mm and feed 0.08 mm/rev)

By keeping the feed rate constant at 0.08 mm/rev and depth of cut at 1.2 mm for two spindle speed of 620 rpm and 800 rpm respectively the variation of flank wear against time has been shown in Fig 4.2(y). It is seen that in the flank wear value at spindle speed 800 rpm is more increasing in nature compare with spindle speed 620 rpm.

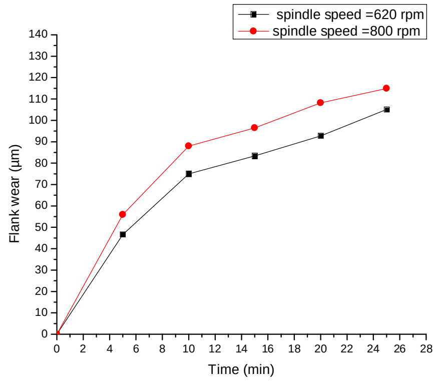


Fig. 4.2(y) Variation of flank wear value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.2 mm and feed 0.08 mm/rev)

Fig. 4.2(z) shows the variation of flank wear with time at four different cutting conditions keeping feed rate at 0.08mm/rev. It is found that with increases in time flank wear is increases for all the cutting conditions (spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm) due to abrasion action. The wear rate is much more at cutting condition of spindle speed of 800 rpm and depth of cut of 1.2 mm than cutting condition of spindle speed of 620 rpm and depth of cut of 1.0 mm. It can be concluded from the flank wear graph that combined effects of spindle speed and depth of cut have significant effect in tool wear.

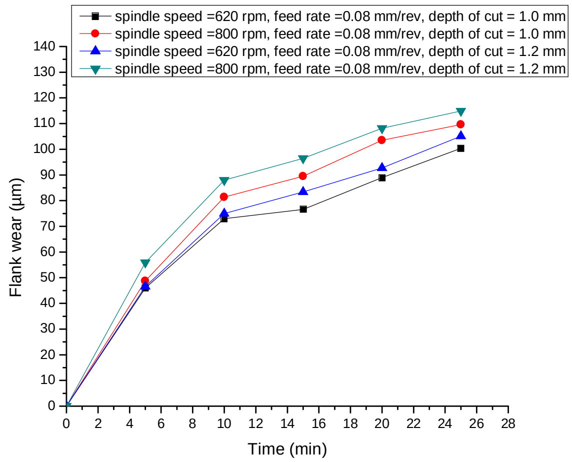


Fig. 4.2(z) Variation of flank wear value with time for four cutting conditions at spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm

4.2.3 Discussion on chip characteristics, surface roughness and tool wear under MQL cutting

➢ **Chip characteristics**

In MQL cutting, generally chips shapes are tubular type in all the cutting conditions and chips are silver in color. Some figures of chip in MQL cutting are shown in Fig 4.3(a) to Fig 4.3(d).

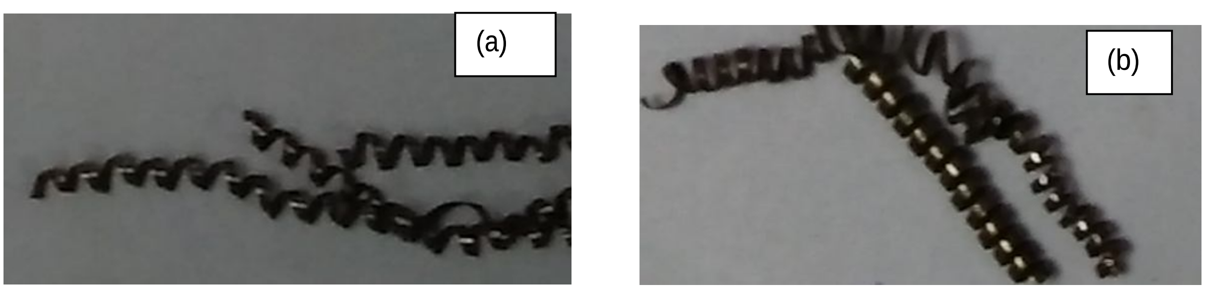


Fig 4.3(a) Chip shape and color at 620 rpm, 0.08 mm/rev and 1 mm depth of cut and (b) Chip shape and color at 800 rpm, 0.08 mm/rev and 1 mm depth of cut

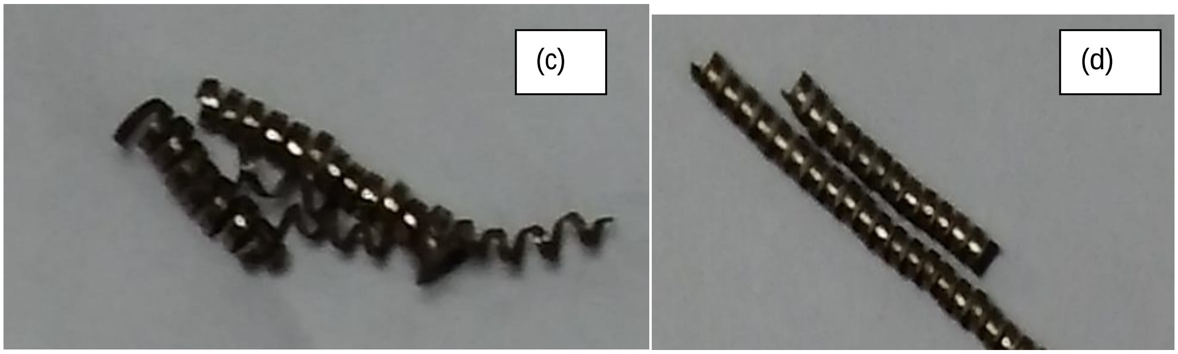


Fig 4.3(c) Chip shape and color at 620 rpm, 0.08 mm/rev and 1.2 mm depth of cut and (d) Chip shape and color at 800 rpm, 0.08 mm/rev and 1.2 mm depth of cut

Generally tubular chip shape with silver color has been obtained in MQL cutting whereas some tubular and helical shape with silver color has been obtained in case of wet cutting condition. But in dry cutting condition helical chip shape with golden color has been noticed. It is in well agreement with the work of Khan et al. [4].

- **Surface roughness**

In case of MQL cutting with different combinations of spindle speed, depth of cut and constant feed 0.08 mm/rev, variations of surface roughness with time are shown in Fig. 4.3(e) to Fig. 4.3(h).

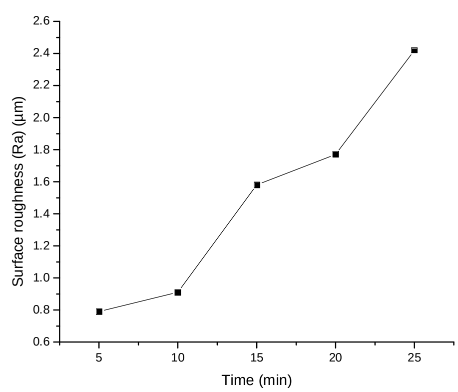


Fig 4.3(e) Variation of surface roughness at spindle speed 620 rpm, Feed 0.08 mm/rev and depth of cut 1.0 mm

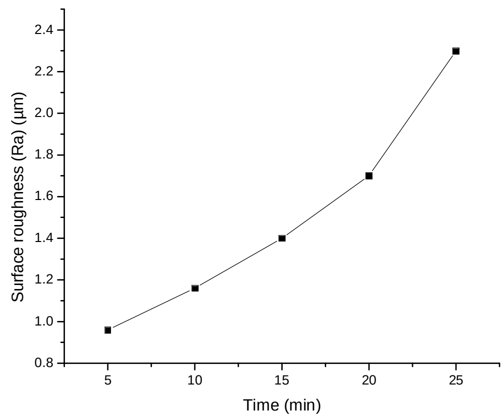


Fig 4.3(f) Variation of surface roughness at spindle speed 800 rpm, Feed 0.08 mm/rev and depth of cut 1.0 mm

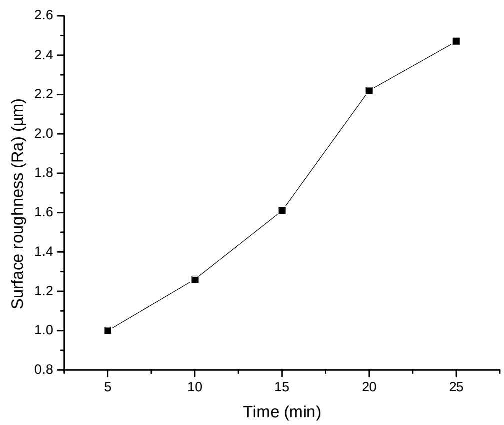


Fig. 4.3(g) Variation of surface roughness at spindle speed 620 rpm, Feed 0.08 mm/rev and depth of cut 1.2 mm

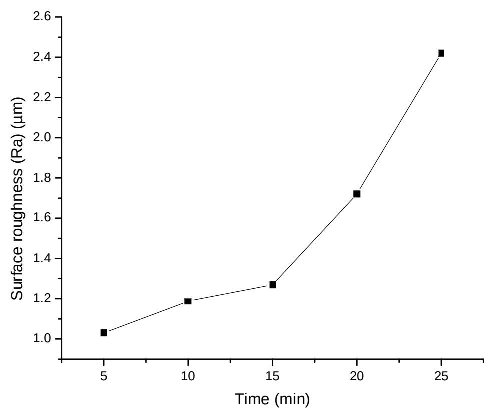


Fig 4.3(h) Variation of surface roughness at spindle speed 800 rpm, Feed 0.08 mm/rev and depth of cut 1.2 mm

In the above figures it is seen that there is a consistent trend of increase in R_a value with increase in time. This may be due to the fact that as the time increases the flank wear increases. This increases the rubbing action between the machined surface and flank surface of the tool and the surface finish is affected..

By keeping the spindle speed constant at 620 rpm and feed at 0.08 mm/rev for two different depths of cuts of 1 mm and 1.2 mm respectively the variation of surface roughness against time has been plotted in Fig 4.3(i). It is seen that in both cases the surface roughness value increases with time due to change in flank angle. But with high value of depth of cut increase in R_a value is observed.

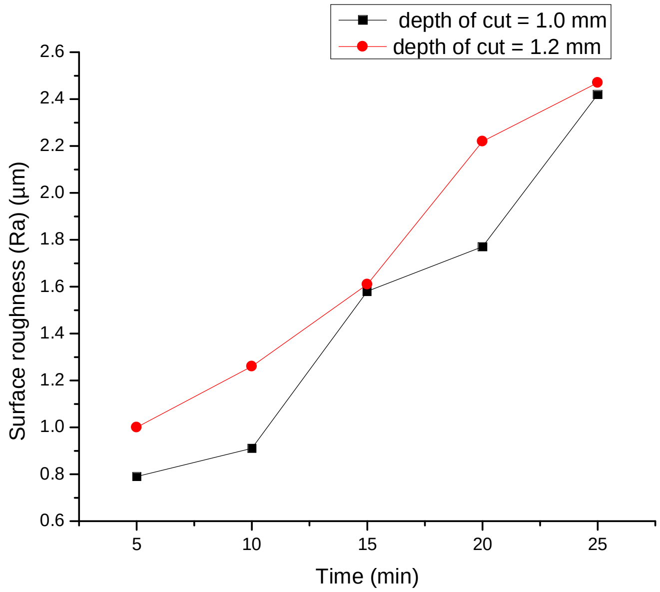


Fig 4.3(i) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 620 rpm and feed 0.08 mm/rev)

Now spindle speed is kept constant at 800 rpm and feed is 0.08 mm/rev, the variation of surface roughness with time for depth of cut 1.0 mm and 1.2 mm respectively is shown in Fig. 4.3(j). In this figure the depth of cut shows a little effect and with higher depth of cut surface finish is not so good as compare to lower depth of cut.

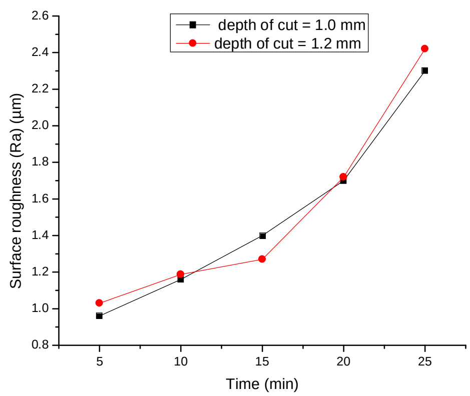


Fig. 4.3(j) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 800 rpm and feed 0.08 mm/rev)

By keeping the depth of cut constant at 1.0 mm and feed at 0.08 mm/rev for two spindle speed of 620 rpm and 800 rpm respectively the variation of surface roughness against time has been shown in Fig 4.3(k). It is seen that in both cases the surface roughness value increases with time due to change in flank angle as with time flank wear increases.

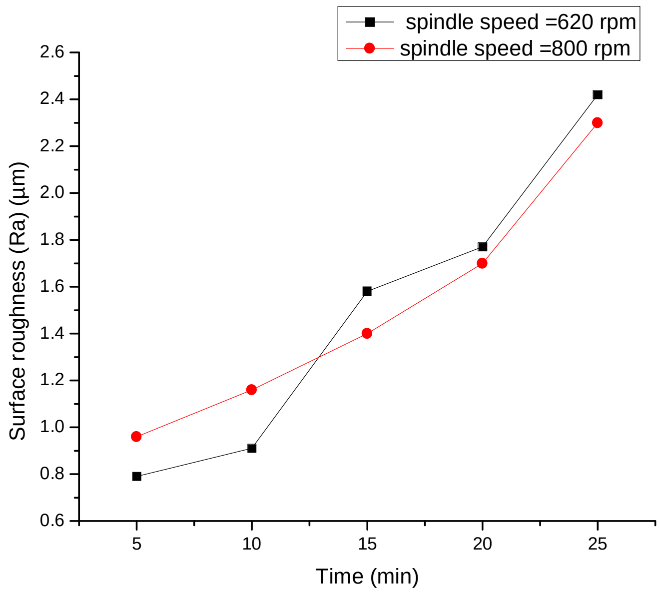


Fig. 4.3(k) Variation of surface roughness value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.0 mm and feed 0.08 mm/rev)

Now spindle speeds have been selected 620 rpm and 800 rpm, feed is kept constant at 0.08 mm/rev and depth of cut at 1.2 mm. The Fig. 4.3(l) shows the variation of surface roughness with time. It is found that the better surface finish has been obtained for spindle speed of 800 rpm and depth of cut at 1.2 mm than the parameter setting of spindle speed of 620 rpm and depth of cut at 1.2 mm.

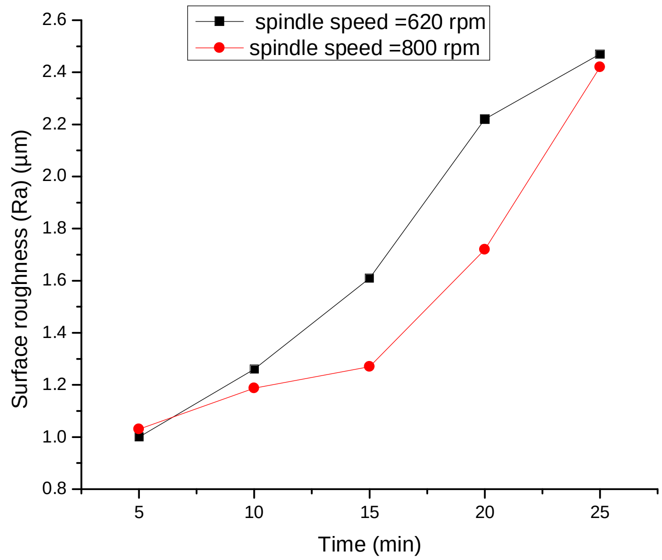


Fig. 4.3(l) Variation of surface roughness value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.2 mm and feed 0.08 mm/rev)

Fig. 4.3(m) shows the variation of surface finish with time at four different cutting conditions keeping feed rate at 0.08mm/rev. It is found that with increase in time surface roughness value increases because of flank wear increase for all the cutting conditions. (spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm).

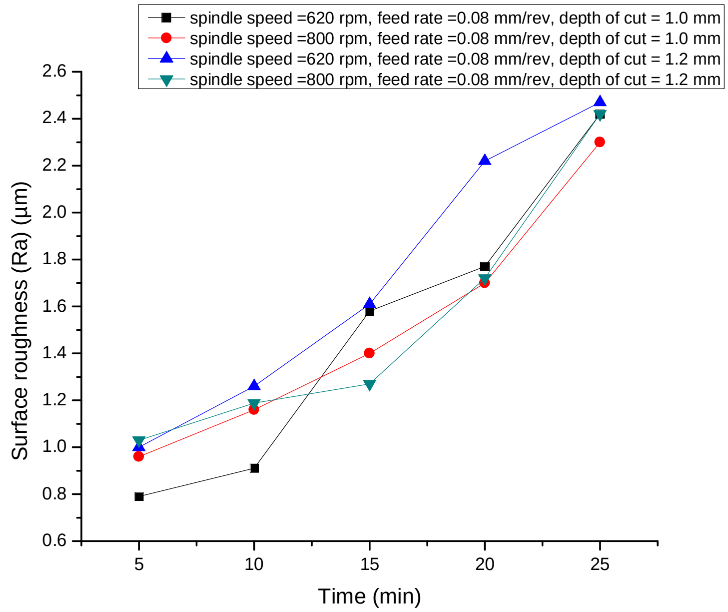


Fig. 4.3(m) Variation of surface roughness value with time for four cutting conditions at spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm

- **Flank wear**

In case of wet cutting for different cutting conditions, the variations of flank wear with time are shown in Fig. 4.3(n), Fig. 4.3(p), Fig. 4.3(r) and Fig. 4.3(t). From these plots an initial break down zone is observed up to 10 min of cut and after that uniform wear zone is obtained. The corresponding views of the flank wear at 200X have been shown in Fig. 4.3(o), Fig. 4.3(q), Fig. 4.3(s) and Fig. 4.3(u).

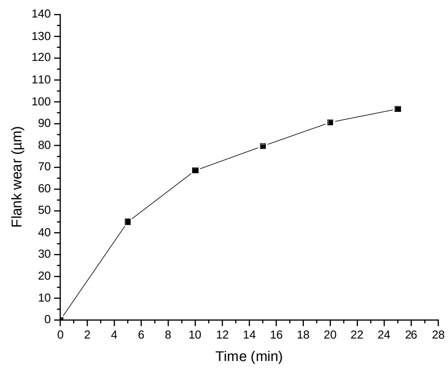


Fig. 4.3(n) variation of flank wear with time at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

Fig. 4.3(o) Microscopic view of wear at cutting condition of at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

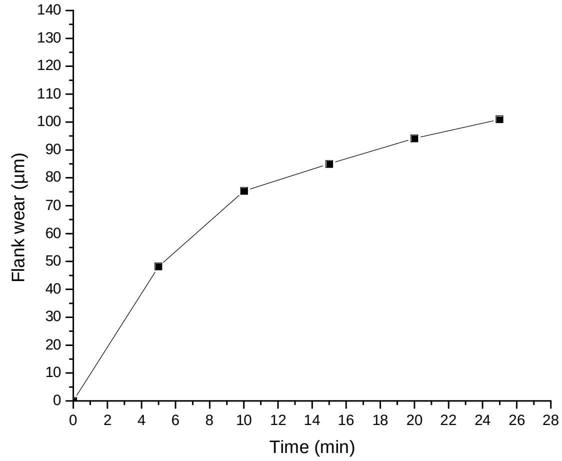


Fig. 4.3(p) variation of flank wear with time at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

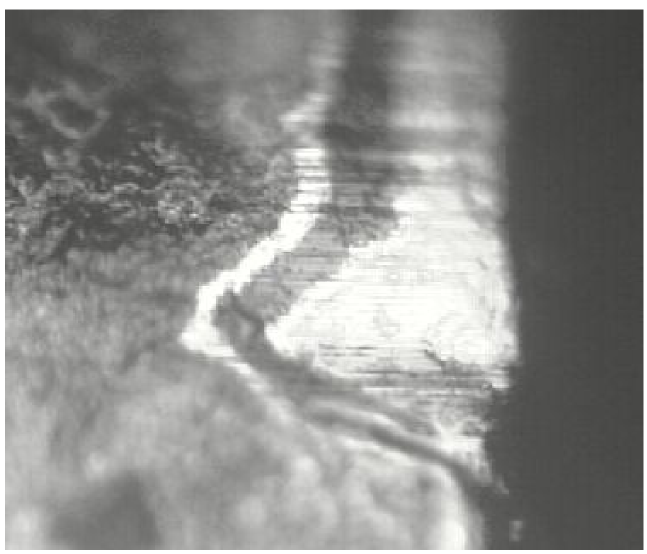


Fig. 4.3(q) The microscopic view of wear at cutting condition of at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

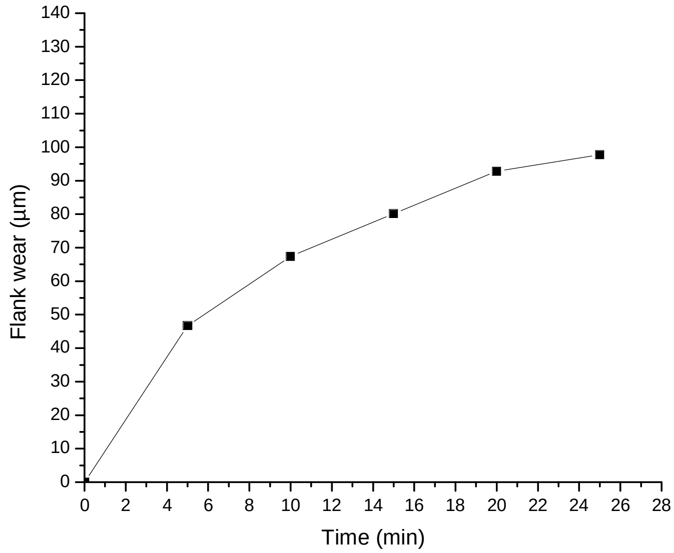


Fig. 4.3(r) variation of flank wear with time at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

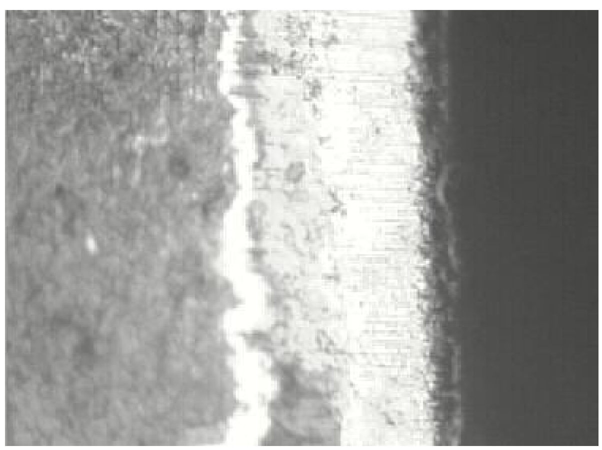


Fig. 4.3(s) The microscopic view of wear at cutting condition of at spindle speed 620 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

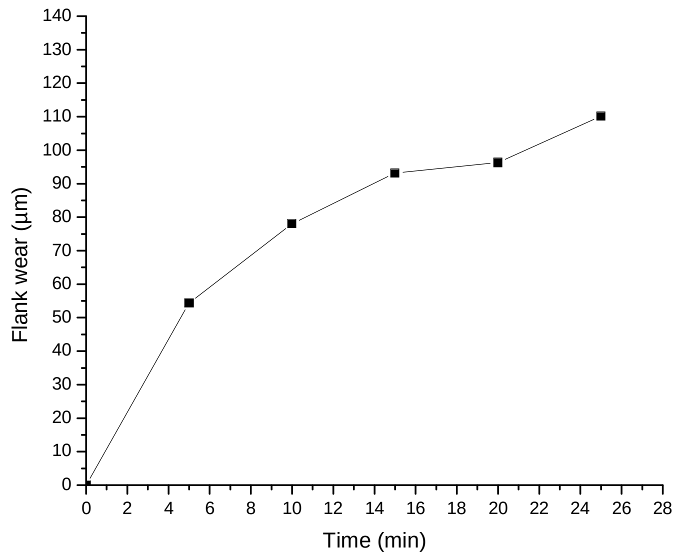


Fig. 4.3(t) variation of flank wear with time at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

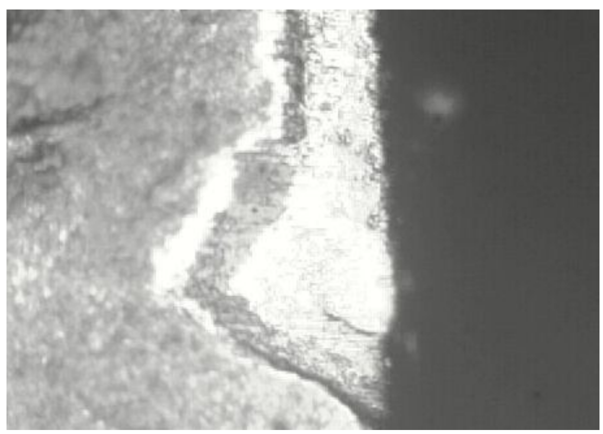


Fig. 4.3(u) The microscopic view of wear at cutting condition of at spindle speed 800 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

Now spindle speed is kept constant at 800 rpm and feed is 0.08 mm/rev, the variation of flank wear with time for depth of cut 1.0 mm and 1.2 mm respectively is shown in Fig. 4.3(v). In this figure the depth of cut shows a negligible effect on tool flank wear. The trend of wear characteristics at depth of cut of 1.0 mm and depth of cut of 1.0 mm is similar.

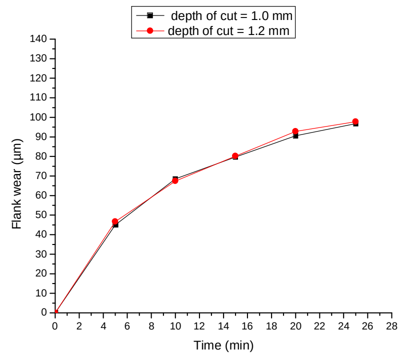


Fig. 4.3(v) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 620 rpm and feed 0.08 mm/rev)

By keeping the spindle speed constant at 800 rpm and feed at 0.08 mm/rev for two different depths of cuts of 1 mm and 1.2 mm respectively the variation of surface roughness against time has been plotted in Fig 4.3(w). It is seen that in both cases the flank wear value increases with time. But the change of depth of cut has not much contribution to the change in the flank wear value.

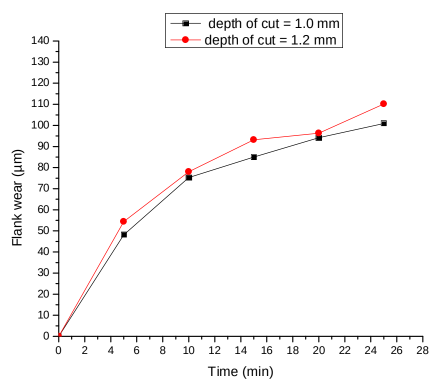


Fig. 4.3(w) Variation of surface roughness value with time for two depths of cuts of 1 mm and 1.2 mm (Spindle speed 800 rpm and feed 0.08 mm/rev)

From the above plot Fig. 4.3(v) and Fig. 4.3(w) it has been seen that depth of cut has very less effect on tool wear rate.

Now spindle speeds have been selected 620 rpm and 800 rpm, feed is kept constant at 0.08 mm/rev and depth of cut at 1.0 mm. The variation of Flank wear with time is shown in Fig.

4.3(x). It has been observed that the flank wear at spindle speed 800 rpm is more as compared to spindle speed of 620 rpm. It is due to much rubbing action takes place at higher spindle speed.

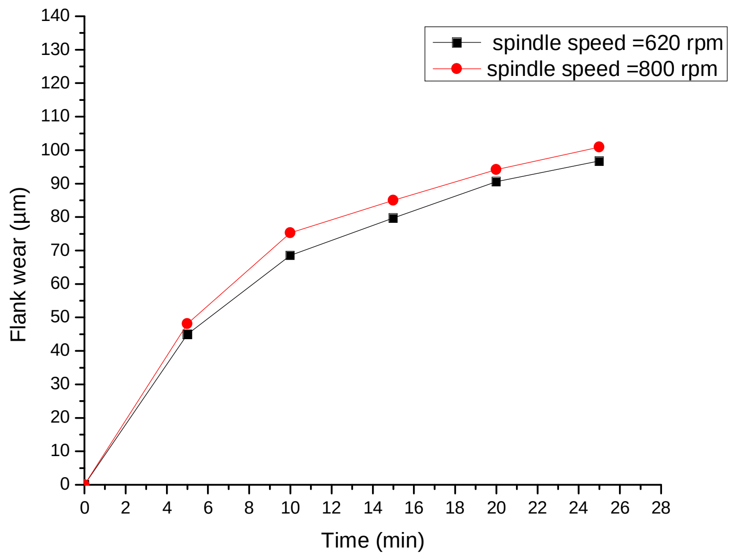


Fig. 4.3(x) Variation of flank wear value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.0 mm and feed 0.08 mm/rev)

By keeping the feed rate constant at 0.08 mm/rev and depth of cut at 1.2 mm for two spindle speed of 620 rpm and 800 rpm respectively the variation of flank wear against time has been shown in Fig 4.3(y). It is seen that in the flank wear value at spindle speed 800 rpm is more increasing in nature compare with spindle speed 620 rpm.

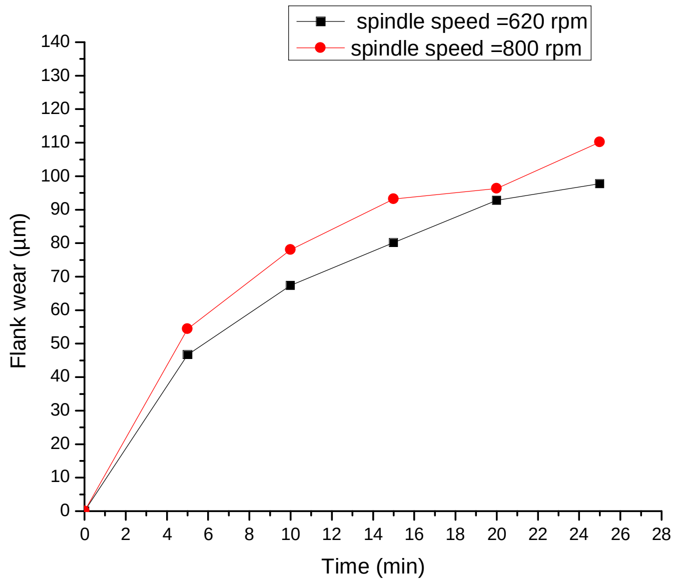


Fig. 4.3(y) Variation of flank wear value with time for two spindle speed of 620 rpm and 800 rpm (Depth of cut 1.2 mm and feed 0.08 mm/rev)

From the above graph Fig. 4.3(x) and Fig. 4.3(y) have been observed that spindle speed has some effect on tool wear because it can be the softening effect of increased temperature in flank position. But in MQL cutting condition this effect is reduced due to less heat generated.

Fig. 4.3(z) shows the variation of flank wear with time at four different cutting conditions keeping feed rate at 0.08mm/rev. It is found that with increases in time flank wear is increases for all the cutting conditions (spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm) due to abrasion action. The wear rate is much more at cutting condition of spindle speed of 800 rpm and depth of cut of 1.2 mm than cutting condition of spindle speed of 620 rpm and depth of cut of 1.0 mm. It can be concluded from the flank wear graph that spindle speed and depth of cut have combined effect on tool wear.

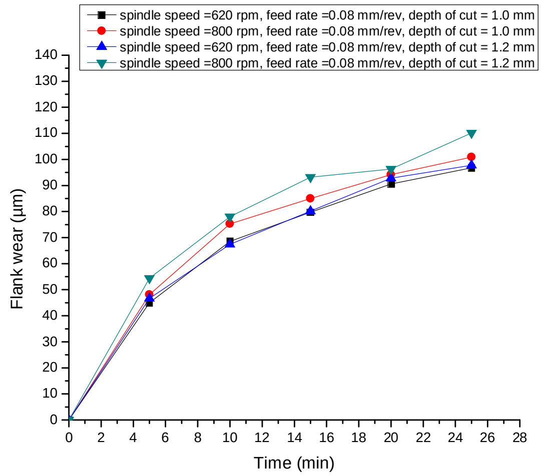


Fig. 4.3(z) Variation of flank wear value with time for four cutting conditions at spindle speed of 620 rpm and depth of cut 1.0 mm, spindle speed of 800 rpm and depth of cut 1.0 mm, spindle speed of 620 rpm and depth of cut 1.2 mm and spindle speed of 800 rpm and depth of cut 1.2 mm

4.2.4 Comparison of surface roughness and flank wear among three different environments

Three different cutting environments (Dry, Wet and MQL) have been used in this experiment. Now comparison on surface roughness and flank tool wear are given following sub section;

- **Surface roughness**

The variation of surface roughness with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm is shown in Fig 4.4(a).

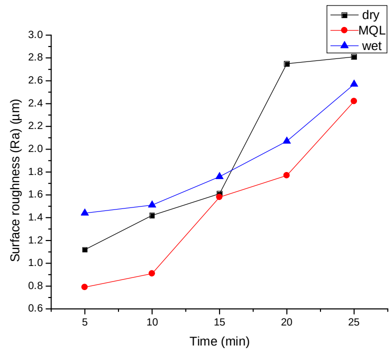


Fig 4.4(a) variation of surface roughness with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

Fig. 4.4(b) shows the variation surface roughness with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 800 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm.

By keeping cutting parameter constant at spindle speed of 620 rpm, feed at 0.08 mm/rev and depth of cut 1.2 mm for three cutting environments (dry, wet and MQL), the variation of surface roughness against time has been plotted in Fig 4.4(c).

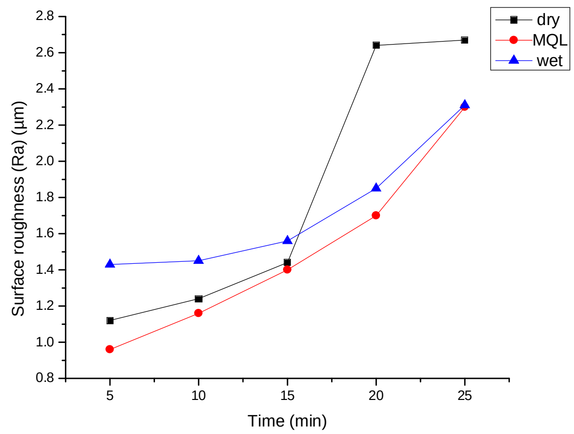


Fig 4.4(b) variation of surface roughness with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 800 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

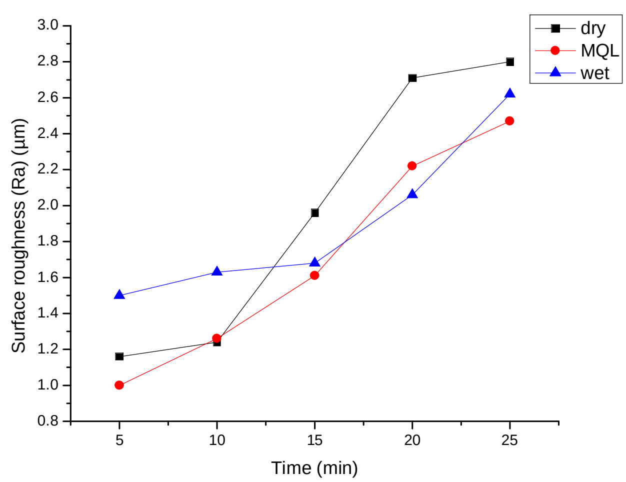


Fig 4.4(c) variation of surface roughness with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 620 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

Now cutting parameters have been selected of spindle speed at 800 rpm, feed rate at 0.08 mm/rev and depth of cut at 1.2 mm under dry, wet and MQL cutting environments. The variation of surface roughness with time is shown in Fig. 4.4(d).

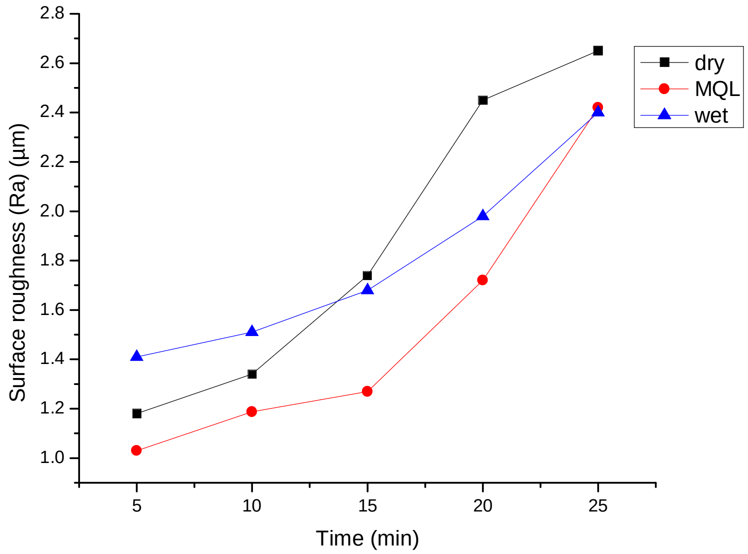


Fig 4.4(d) variation of surface roughness with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 800 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

From the above plots it has been noticed that surface finish is improved under MQL condition as with this the heat generated has affected the work piece and the tool to little extent. Also the flank wear is less with MQL which in turn improves the surface finish. It has been observed that at MQL condition surface roughness is reduced by 20% as compared to wet & 16% as compare to dry cutting conditions.

- **Flank wear**

Fig. 4.4(e) shows the variation flank wear with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm.

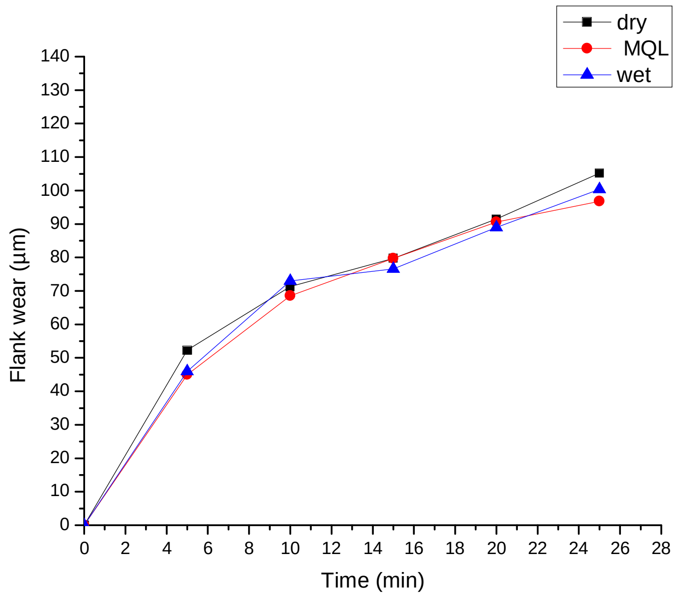


Fig 4.4(e) variation of flank wear with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

By keeping cutting parameter constant at spindle speed of 800 rpm, feed at 0.08 mm/rev and depth of cut 1.0 mm for three cutting environments (dry, wet and MQL) and the variation of flank wear against time has been plotted in Fig 4.4(f).

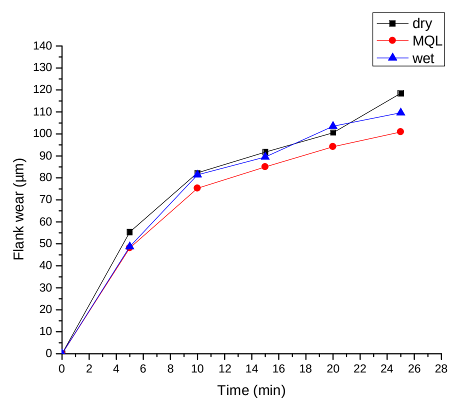


Fig 4.4(f) variation of flank wear with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 800 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm

The variation of flank wear with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 620 rpm, feed 0.08 mm/rev and depth of cut 1.0 mm is shown in Fig 4.4(g).

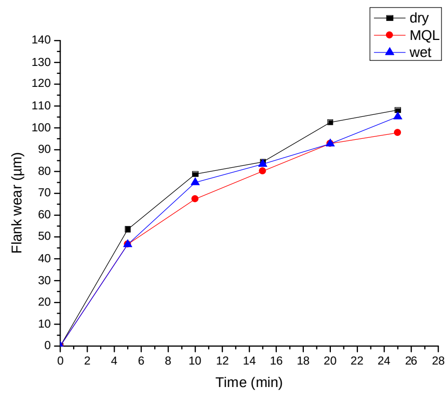


Fig 4.4(g) variation of flank wear with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 620 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

Now cutting parameters have been selected of spindle speed at 800 rpm, feed rate at 0.08 mm/rev and depth of cut at 1.2 mm under dry, wet and MQL cutting environments. The variation of flank wear with time is shown in Fig. 4.4(h).

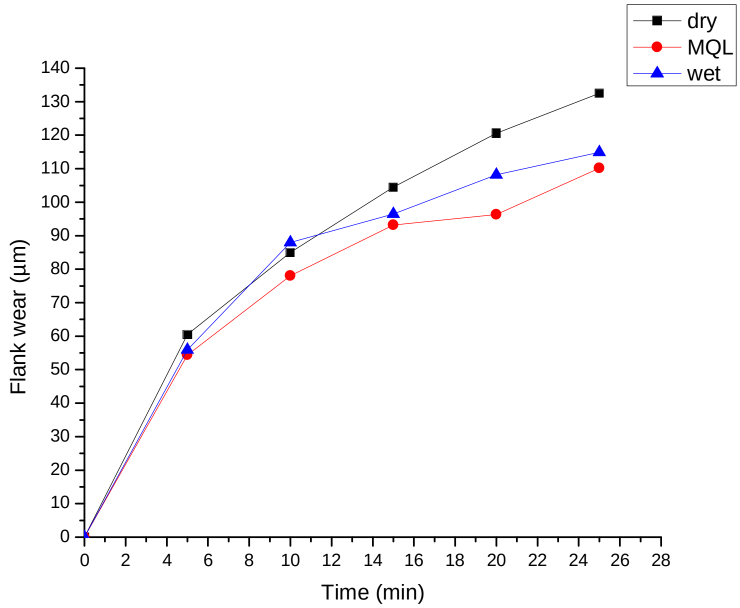


Fig 4.4(h) variation of flank wear with time under three different cutting environments (dry, wet and MQL) at cutting condition of spindle speed of 800 rpm, feed 0.08 mm/rev and depth of cut 1.2 mm

From the Fig 4.4(e) to Fig 4.4(h), it can be concluded that flank wear progression rate of MQL cutting condition is lower compared to dry and wet cutting environments. Max flank wear has been observed in dry cutting environment and it may due to more heat generated at dry cutting condition. In wet cutting condition wear propagation is in between MQL and dry conditions since a fluid film boundary layer is formed at tool-work piece interface. In MQL wear growth rate is less because the pressurized coolant has been applied into the interface, so coolant's action is much more efficient. It has been seen that the flank wear at MQL cutting condition reduces by 6% compared to wet and 10% compared to dry cutting conditions.

The determination of tool-life equation presents many practical difficulties since the variables involved are numerous and the tests are often time consuming and expensive. Various methods have been developed for evaluating tool life; mainly conventional tool life test and taper turning test. But conventional one is more expensive and time consuming. So for the present work, taper turning test for determination tool life of the cutting insert has been conducted.

From taper turning test, the exponent and the constant of the Taylor's Tool life equation have been determined and given in the Table. 4.4.

Table 4.4. The exponent and the constant of the Taylor's Tool life equation

Cutting condition	Spindle speed (rpm)	Cutting velocity (mm/min)	Feed rate (mm/rev)	Depth of cut (mm)	Tool life (min)	"n" value of Taylor's Tool life Equation	"C" value of Taylor Tool Life Equation	"α" value in graph
Dry	620	136.5	0.08	1.0	100	0.49	1303.565	26.5
Wet	620	136.5	0.08	1.0	104.34	0.52	1530.126	27.8
MQL	620	136.5	0.08	1.0	104.1	0.577	2443.246	30
Dry	800	175.5	0.08	1.0	87.82	0.414	870.5232	22.5
Wet	800	175.5	0.08	1.0	89.17	0.4578	1066.456	24.6
MQL	800	175.5	0.08	1.0	101.8	0.624	1990.494	32
Dry	620	136.5	0.08	1.2	87	0.48	1497.085	26
Wet	620	136.5	0.08	1.2	95	0.466	1465.198	25
MQL	620	136.5	0.08	1.2	102	0.53	2036.269	28
Dry	800	175.5	0.08	1.2	70	0.36	810.0511	20
Wet	800	175.5	0.08	1.2	88	0.4	1052.132	22
MQL	800	175.5	0.08	1.2	97	0.44	1313.58	24

CHAPTER 5

Conclusion and Future Scope of Work

5.1 Conclusion

In the present work, the cutting performances of coated inserts in MQL cutting have evaluated in terms of tool life and surface finish, and compared with those in dry and wet cutting using bio degradable refined soyabean oil as the cutting fluid for straight turning of AISI 1050 steel. Spindle speeds have been set at relatively higher values of 600 rpm and 800 rpm. Depths of cut have been selected at 1.0 mm and 1.2 mm keeping feed rate constant at 0.08 mm/rev. Throughout this study the supply rates of soyabean oil in MQL machining and wet cooling application has been kept constant at 90 ml/h and 20 l/h respectively. The following conclusion can be drawn after completion of experiment and upon studying the results:

- MQL has provided significant improvements in respect of chip formation modes, tool wear and surface finish throughout the range of rpm and depth of cut undertaken mainly due to reduction in the average chip–tool interface temperature.

- The significant contribution of MQL jet in machining the high carbon steel by the carbide insert undertaken has been the reduction in flank wear, which would enable improvement in tool life allowing higher spindle speed. Such reduction in tool wear might have been possible for retardation of abrasion.

- Surface finishes also improved mainly due to reduction of wear and damage at the tool-tip by the application of MQL.
- The flank wear at MQL cutting condition has been reduced by 6% compared to wet cutting condition and 10% compared to dry cutting condition.
- **S**urface finish has been increased by 20% compared to wet cutting and 16% compared to dry conditions.

5.2 Future Scope of Work:

- This investigation may be extended by measuring temperature, feed force; thrust force and cutting force.
- The cutting performances of soyabean oil are needed to be examined on various types of work materials and under wider range of cutting parameters in future work.
- Single objective optimization and multi-objective optimization may be carried out by using Taguchi, Response Surface Methodology (RSM).
- Other types of coated and uncoated cutting tool may be used for the same work piece for further work.
- In this experiment soyabean oil has been used as cutting fluids. Other types of vegetable oils like mustard oil, sunflower oil, coconut oil, cottonseed oil etc. may be used as cutting fluid for future work.
- In this investigation MQL experiment is done at 5 bar pressure, some investigation may be done by changing the pressure.
- A chemical treatment may be done on soyabean oil for increase in smoke point and then this investigation can be done for better result.

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