Effect of Minimum Quantity of Lubricant (MQL) on Tool Wear and Product Quality in Machining Steel by Coated Carbide Insert

By

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This Thesis work is dedicated to

My beloved

Parents

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V_c	Cutting velocity
S_0	Feed rate
t	Depth of cut
V_B	Average principal flank wear
V_M	Average maximum flank wear
V_S	Average auxiliary flank wear
R_a	Average surface roughness
SEM	Scanning electron microscope

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Abstract

The concept of Minimum Quantity Lubrication (MQL) sometimes referred to as near dry lubrication or micro lubrication has been advocated since a decade ago as a means of addressing the issue of environmental troublesome. Minimum Quantity Lubrication mentions to the use of cutting fluid of only a little amount usually of a flow rate of 50 to 500 ml/hour–which is about three to four orders of scale lower than the amount commonly used in flood cooling condition, for example, up to 10 liters of fluid can be supplied per minute. Saving lubricant costs and tool /workpiece/machine cleaning cycle time the minimization of cutting fluid also leads to economical benefits.

A number of studies have shown that MQL machining can show satisfactory performance in practical machining operations. But, there has been little investigation of the cutting fluids to be used in MQL machining. In this regard the proposed research work has been carried out with a view to study the effects of Minimum Quantity Lubrication (MQL) by water soluble cutting fluid on the cutting performance of medium carbon steel, as compared to completely dry and wet machining in terms of tool wear reduction, tool life increment and machined surface integrity. Based on the process parameters (speeds, feeds and depth of cut) an approach has also been performed to recognize the apt MQL nozzle position for better cooling action. In the study, the minimum quantity lubrication will be provided with a spray of air and water soluble cutting fluid. Significant progress

has been made in dry and semidry machining recently, and Minimum Quantity Lubrication (MQL) machining in particular has been accepted as a successful semi-dry application because of its environmentally friendly characteristics.

Compared to the dry or wet machining, MQL machining performed much better-quality mainly due to considerable in cutting zone temperature enabling favorable chip formation and chip-tool interaction. It also provides substantial reduction in tool wear, which augment the tool life, and surface finish. Moreover, it provides environment friendliness (maintaining neat, clean and dry working area and improves the machinability characteristics.

Chapter-1

Introduction

Turning plays an important role in machining process yielding good surface finishing. It is one of the machining processes, in which sliding a hard cutting tool cause removal of material over a softer material and yielding different sorts of chips. The main course of action variables in this case are, the feed rate, the cutting speed, and the depth of cut. Feed rate is defined as the distance the tool advances into or along the job each time the tool point passes a certain position in its travel over the surface during one rotation of the Job. Cutting speed is either given as the rotational velocity of the job or as the linear tangential velocity of the job at the tip of the cutting tool, and cutting depth is the radial distance taking on the cutting tool and the Job.

1.1 High Production Machining

Effective implementation essentially needs to be technically feasible, technologically acceptable, and economically viable for all manufacturing processes. There has been a great concern about environment-friendliness in and out of the manufacturing shops of the modern industries and society.

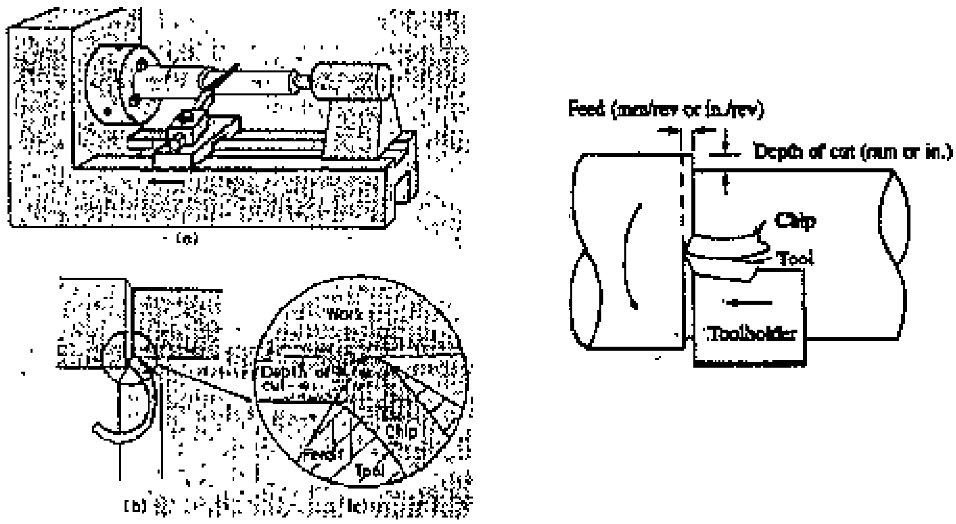

Fig.1.1 Traditional turning process [**Trent 1977; Kalpakjian 1997**]

Machining Like turning and grinding to attain the desired accuracy and good surface finish. The performance and service life of any engineering component counts on their material, dimensional and form accuracy and surface excellence.

In order to meet the challenges throw by global cost competitiveness and liberalisation, manufacturing by machining and grinding demand for higher productivity, product quality and more economy, insists high material removal rate and higher stability and longer life of the cutting tools.

High production machining with high cutting velocity, feed and depth of cut is naturally related with generation of large amount of heat and high cutting temperature. Such high cutting temperature not only reduces tool life and dimensional accuracy but also damage the surface integrity of the product

On the other hand, high cutting temperature accelerates the growth of tool wear and also enhances the probability of premature failure of the tool by plastic deformation and thermal fracturing. The surface quality of the products also deteriorates with the increase in cutting temperature due to built-up-edge formation, oxidation, rapid corrosion and induction of tensile residual stress and surface micro-cracks. These problems are more predominant in grinding where cutting temperature is, as such, very high due to much higher specific energy requirement and cutting velocity. Longer cuts under high cutting temperature cause thermal expansion and deformation of the job, particularly if the job is small and slender in size, which leads to dimensional and form inaccuracy. Such problem becomes more acute and serious if the work materials are very strong, heat resistive and hard subjected to dynamic or shock loading during their operations. Therefore, it is essential to lessen the cutting temperature as far as possible.

Generally in industries, the machining temperature and its detrimental effects are generally reduced by three ways- **firstly**, proper selection of process parameters and geometry of the cutting tools. **Secondly**, using heat and wear resistant cutting tool materials like carbides, coated carbides and high performance ceramics (CBN and diamond are extremely heat and wear resistive but those are too expensive and are justified for very special work materials and requirements where other tools are not effective). **Thirdly**, proper selection and application of cutting fluid.

The conventional types and methods of application of cutting fluid have been found to become less effective with the increase in cutting velocity and feed when the cutting fluid cannot properly enter the chip-tool interface to cool and lubricate due to bulk plastic contact of the chip with the tool rake surface. Cutting fluid not only cools the tool and job but also provides lubrication and cleans the cutting zone and protects the bare finished surface from contamination by the damage gases present in the atmosphere. Besides that, often in high production machining early failure of the cutting tool takes place by fracturing due to close curling of the chips and thermal shocks by using the cutting fluid.

The conventional type and method of application of cutting fluids causes major socio-economic problems those are:

i) possible damage of the machine tool by corrosion and mixing of the cutting fluid with the lubricants.

ii) inconveniences due to wetting and dirtiness of the working zone.

iii) requirement of additional systems for local storage, pumping, filtration, recycling, re-cooling, large space and disposal of the cutting fluid, which causes water pollution as well as soil contamination.

Ample researches have been carried out and are still going on in the way that possible means of dry, clean, neat and pollution free machining like turning and grinding. Minimum Quantity Lubrication (MQL) by agents like Water soluble cutting fluids appears to be a promising technique for effective cooling minimizing the problems associated with conventional cutting fluid applications (flood cooling). It is necessary to explore the possible technological benefits of such Minimum Quantity Lubrication (MQL) and optimise it.

But it is also essential to be assured that productivity and overall economy are conducive while deriving the environmental benefits of Minimum Quantity Lubrication (MQL).

1.2 Selection of Cutting Tool

Depending on machining conditions and workpiece properties, different degrees of hardness or toughness are required. Generally, increased hardness improves wear resistance but is associated with decreased toughness. All cutting operations require tool materials that can withstand the difficult conditions produced during machining. All cutting tools face primarily three problems, this are-

i) Heat generated during the cutting process

ii) Wear at the cutting edge,

iii) thermo-mechanical shock.

Characteristics including hardness, toughness, wear resistance, and chemical stability that allow tool materials to stand up to the cutting process.

Silicon nitride (Si_3N_4) can be used as a cutting tool, but does not sinter easily to full density. Additions are often made to assist sintering, but hot pressing is typically required to achieve good strength. Similar to sialon tools, diffusion into iron makes Si_3N_4 tools unsuitable for machining steels. They are generally restricted to gray cast iron and some nickel-based alloys [**Jack 1986**].

High-speed steels (HSS) are important to discuss due to their extensive use in metal cutting as well as to demonstrate the need for ceramic tools. High-speed steels have the lowest hardness and highest fracture toughness of general use tools. The main reason high-speed steel tools are not used more extensively is that they soften significantly at temperatures above 500°C. This softening behavior limits high-speed steels to relatively low cutting speeds on softer materials, and has caused the need for carbide and ceramic cutting tools that maintain hardness at elevated cutting temperatures.

To machine hard materials in applications where carbide tools do not maintain hardness at high cutting speeds and alumina based tools do not offer adequate toughness, Polycrystalline cubic boron nitride cutting tools have been developed. CBN tools are very expensive and justified for very special work materials and requirements where other tools are not effective. Ceramic materials with high hardness, in particular, cubic boron nitride (CBN), have been employed in machining hardened steel **[Tonshoff and Kaestner 1991** and **Naikai et al. 1991]**. The main advantages of CBN tools are that they maintain hardness even at very high temperatures [~1800 HV at

1000°C from [**Tabuchi et al. 1978**], have low solubility in iron, and good fracture toughness for a ceramic [**Bossom 1990**]. After all there have been a lot of reports and successful examples of using CBN tools for hard turning, the practices in the industry are still not widespread [**Chou 2003**].

Machining at higher cutting speeds (and increased production rates), Carbide tools were, therefore, developed in the 1930's [**Kalpakjian 1997**]. About 75% of the machining market these tools are now consumed. They are sometimes called sintered carbides or cemented carbides because the tools are typically pressed and sintered from ceramic powders (often with a cobalt binder material). There are two basic subsets of carbide tools: tungsten carbide (WC) and titanium carbide (TiC), WC tools being the most prevalent.

However, an optimal grain size and cobalt percentage must be determined to allow the hardness and toughness required for a particular cutting operation. Hardness and wear resistance can be improved by reducing the grain size of the WC particles, which are typically in the range of 0.5-5 µm [**Edwards 1993**]. Pure WC is very hard, but also brittle. To improve toughness, WC powder is mixed with 5-15% cobalt (weight percentage).

Chapter-2

Literature Review

Huge research and investigations have been done as of today in many parts of the world on machinability of different materials mainly in respect of cutting temperature, cutting speed, dimensional accuracy, surface integrity, wear, chip tool interaction and with and without (dry machining) using cutting fluid. Research has also been conducted on control machining and their technological effects particularly in temperature intensive machining and grinding by MQL In this section a concise review of some of the important and interesting contributions in the closely related areas is presented.

2.1 Effects and Control of Cutting Temperature

Generation of heat and high cutting temperature at cutting zone is inherent characteristic of machining. Cutting tool may lose their form stability quickly or wear out rapidly if not enough hot hard at such elevated temperature resulting in dimensional inaccuracy of the product and shorter tool life. The magnitude of this cutting temperature increases, though in different degree, with the increase of cutting velocity, feed and depth of cut, as a result, rise in temperature is a common phenomenon for high production machining. Increase in strength and hardness of the work material enhances this problem further.

[Jawahir and **van Luttervelt 1993]** observed machining ductile metals producing long chips; the chip-tool contact length has a direct influence on the cutting temperature and thermo-chemical wear of cutting tools.

Generally usual flank wear and crater wear the cutting tools often attain notching on the flanks and grooving on the rake surface at the outer ends of the engaged portions of the cutting edges. On the major cutting edge, the grooving wear occurs at the extreme end of the depth of cut and is characterized by deeper abrasion of the tool edge. On the end cutting edge, the grooving wear is characterized by smaller multiple notches. Several mechanisms have been proposed **[Solaja 1958]** to explain grooving wear. Such as

i) formation of thermal cracks due to steep temperature gradient

ii) development of a work-hardened/abrasive oxide layer on the cut surface

iii) presence of side-spread material at the edges of a newly cut surface and

iv) fatigue of tool material due to cutting force fluctuations at the free surface caused by lateral motions of the edges of the chip.

The heat generated during machining also raises the temperature of the cutting tool tips and the work-surface near the cutting zone [**Trent 1984**]. Due to such high temperature and pressure the cutting edge deforms plastically and wears rapidly, which lead to dimensional inaccuracy, increase in cutting forces and premature tool failure. If the cutting temperature is high and not controlled, it impairs the surface integrity by oxidation and introducing residual stresses, micro-cracks and structural changes and worsens the surface topography.

Hardness, plastic modulus and the fracture toughness of the tool decline with increase in cutting temperature, which accelerates tool wear rate reported by [**Reed et al. 1983**]. Moreover, thermal stresses in the tool increase with the temperature yielding in premature failure of the tool and more cracks in the tool. Mechanical and chemical damage of the finished surface are also caused by high cutting temperature

[**Vleugels et al. 1995**] observed that the contact length between the tool and chip has a direct influence on the cutting temperatures and the amount of heat energy that is dissipated in the tool which enhances thermally activated chemical wear. Maximum temperature is found to develop on the rake face of the tool, at a certain distance from the cutting edge, where cratering occurs. The amount of energy dissipated through the rake face of the tool also raises the temperature at the flanks of the tool.

The high specific energy required in machining under high cutting velocity and unfavorable condition of machining results in very high temperature which reduces the dimensional accuracy and tool life by plastic deformation and rapid wear of the cutting points [**Chattopadhyay** and **Bhattacharya 1968; Chattopadhyay** and **Chattopadhyay 1982** and **Singh et al. 1997**]. On the other hand such high temperature, if not controlled, impairs the surface integrity of the machined component by severe plastic flow of work material, oxidation and by inducing large tensile residual stresses, micro cracks and subsurface cracks. This problem is further intensified while machining for faster material removal in bulk and finishing very hard, strong and difficult-to-machine materials, which are gradually adventing with vast and rapid developments in the modern areas, like aerospace technology and nuclear science.

Past research has been focused on the temperature and its distribution in the cutting zone because it is believed that it has a direct impact on tool life [**Chao and Trigger 1955**]. The primary function of cutting fluids is to reduce this cutting temperature and increase tool life [**Shaw et al. 1951**]. The cutting fluids are believed to reduce cutting temperature either by removing heat as a coolant or reducing the heat generation as a lubricant. In addition, the cutting fluid has a practical function as a chip-handling medium [**Beaubien 1964**]. Cutting fluids also help in machining of ductile materials by reducing or preventing formation of a built-up edge (BUE), which degrades the surface finish [**Heginbotham** and **Gogia 1961**].

Usually the high cutting temperature is controlled by profuse cooling [**Alaxender et al. 1998; Kurlmoto** and **Barroe 1982** and **Wrethin et al. 1992**]. But such profuse cooling with conventional cutting fluids is not able to solve these problems fully even when employed in the form of jet or mist. With the advent of some modern machining process and harder materials and for demand for precision machining, the control of machining temperature by more effective and efficient cooling has become extremely essential.

Generally, suitable cutting fluid is employed to reduce this problem through cooling and lubrication at the cutting zone. The ineffectiveness of lubrication of the cutting fluid at high speed machining is attributed [**Shaw et al. 1951**] to the inability of the cutting fluid to reach the actual cutting zone and particularly at the chip-tool interface due to bulk or plastic contact at high cutting speed. But [**Cassin** and **Boothroyed 1965**] has been experienced that lubrication is effective at low speeds when it is accomplished by diffusion through the workpiece and by forming solid boundary layers from the extreme pressure additives, but at high speeds no sufficient lubrication effect is evident.

The cooling and lubricating effects by cutting fluid [**Merchant 1958** and **Kitagawa et al. 1997**] influence each other and diminish with increase in cutting velocity. Since the cutting fluid does not enter the chip-tool interface during high speed machining, the cutting fluid action is limited to bulk heat removal only. **[Mazurkiewicz 1989]** reported that a coolant applied at the cutting zone through a high pressure jet nozzle could reduce the contact length and coefficient of friction at chip-tool interface and thus could reduce cutting forces and increase tool life to some extent.

A cutting fluid may impart two more actions, namely the mechanical strength reducing action and the electro-chemical action. The mechanical strength reducing action (known as the Rebinder effect) seemed to be negligible when steel jobs are machined at moderate cutting speeds with carbide tools **[Kurimoto and Barroe 1982]**. The influence of the electric current flowing through the cutting zone on the rate of tool wear is also well known **[Ellis and Barrow 1969]**. However, most commercial cutting fluids are non electro-conductive, such as the situation with respect to current flow will not vary significantly from the dry cutting case. The electrochemical action is treated as a corrosion phenomenon in respect of tool wear.

The machining temperature could be reduced to some extent by improving the machinability characteristics of the work material metallurgically, optimizing the tool geometry and by proper selection of the process parameters **[Muraka 1979; Dieter 1981** and **Jawahir 1988]**. Some recent techniques have enabled partial control of the machining temperature by using heat resistance tools like coated carbides, CBN etc. The thermal deterioration of the cutting tools can be reduced **[Narutaki** and **Yamane 1979]** by using CBN tools. If properly manufactured, selected and used, CBN tool provides much less cutting forces, temperature and hence less tensile residual stresses [**Davies et al. 1996**]. But CBN tools are very expensive.

It was reported [**Alaxender et al. 1998**] that coolant injection offers better cutting performance in terms of surface finish, tool force and tool wear when compared to flood cooling. A recent development [**Chandrasekaran et al. 1998**] in this context is the use of CO_2 snow as the coolant in machining. This is feasible if CO_2 in liquid form under pressure (60 bars) is fed to the cutting zone and diffused through a capillary jet. This results in a change of state and the formation of CO_2 snow (endothermic reaction resulting in a temperature of -79^{0}C). Earlier investigations [**Thoors and Chandrasekaran 1994**] observed that CO_2 snow could function as a good cutting fluid/coolant under certain circumstances, which are very much related to the tool-work combination and the actual mode of feeding the coolant to the cutting zone. Manufacturers are forced to re-evaluate their manufacturing processes and reduce or eliminate their waste streams. The waste streams present in machining include cutting fluid flow, chip flow, and cutting tool usage.

Proper selection and application of cutting fluid generally improves tool life. At low cutting speed almost four times longer tool life was obtained [**Satoshi et al. 1997**] by such cutting fluid. But surface finish did not improve significantly.

During machining, the cutting tool generally undergoes [**Trent 1983**] both flank wear and crater wear. Flank wear generally causes an increase in the cutting forces, dimensional inaccuracy and vibration. Crater wear takes place on the rake face of the tool where the chip slides over the tool surface.

Wearing of cutting tools not only causes loss of the cutting edges or tips of the inserts but loss of the entire insert after wear of all the corners. From an environmental perspective, therefore, the significant waste is not the portion of the tool worn away by the tool-work contact, but the remaining portion of the tool that is disposed after its useful life [**Sheng and Munoz 1993**].

Recent development of pollution-prevention legislation and a growing consumer, demand for pollution free manufacturing processes. Safety and health of the operators, as well as the requirements to enforce the environmental protection laws and occupational safety and health regulations are compelling the industry to consider healthy machining process instead of using conventional process.

Cutting fluids are widely used in machining operations to obtain accuracy of part dimensions, longer tool life and in some cases better surface finish. The research literature identifies two primary functions of cutting fluids in machining operations: lubrication to reduce process friction and cooling to remove process generated heat.

2.2 Mechanisms of Tool Wear

Most tool wear can be described by a few mechanisms, which include: abrasion, adhesion, chemical reaction, plastic deformation, and fracture. Several types of wear mechanisms depend on metal cutting parameters (primarily cutting speed), work piece material as well as cutting tool. Like most wear applications, tool wear has proved difficult to understand and predict.

These mechanisms produce wear scars that are referred to as flank wear, crater wear, notch wear, and edge chipping, as illustrated in Fig.2.2. When machining metals with carbide or oxide inclusions, metal matrix composites, carbides, and ceramics, abrasive wear mechanism can dominate. This mechanism results from sliding of hard abrasive inclusions in the workpiece material across the face of a cutting tool. Adhesion results from friction welding of the workpiece and tool material, which can cause portions of the cutting tool to be plucked out. Some amount of abrasive and adhesive wear is desired to allow gradual tool wear and prevent premature tool fracture or chipping of the cutting edge [**Mehrotra 1998**]. Chemical reactions between the cutting tool and workpiece (or environment) can also lead to accelerated tool wear or premature tool fracture. A good example is cutting steel with polycrystalline diamond tools, where diffusion of carbon into the steel dramatically decreases tool life. Plastic deformation can also shorten tool life, but this is rarely a problem for ceramics. Finally, aggressive cutting conditions can yield excessive mechanical and thermal loads and cause fracture or chipping.

Ceramics offer the advantages **[Adams 1991** and **Amin 1991]**. of increased resistance to abrasion due to increased hardness, improved chemical stability, better hardness retention at the elevated temperatures typical in metal cutting (specially steel cutting tools), and superior heat dispersal during cutting. The major limitation of ceramic cutting tools is low fracture toughness. Ceramic tools can fracture prematurely if aggressive or interrupted cuts are made, machine vibration is excessive, or thermal shock occurs. By eliminating or reducing these problems, ceramic tools can achieve adequate tool life and yield improved material removal rates. To compensate for the brittle nature of ceramic tools, strong cutting geometries are required.

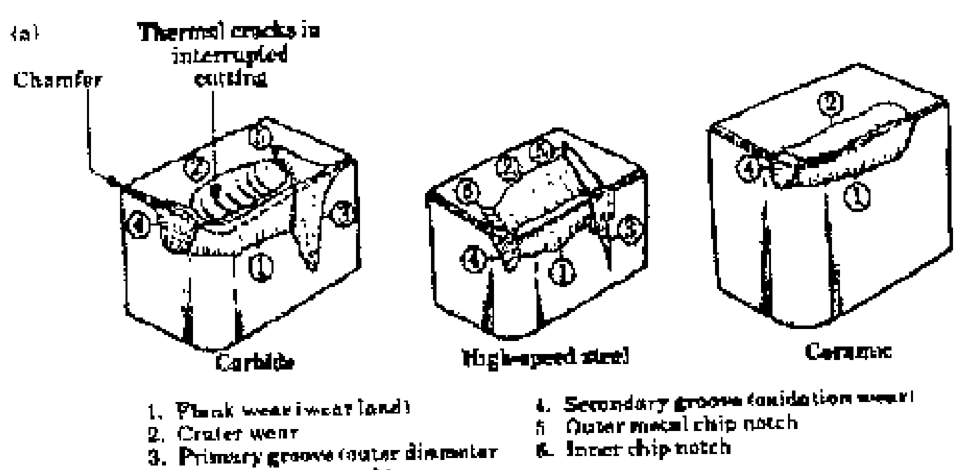

Fig.2.2 Tool wear mechanisms **[Kalpakjian 1997]**

Crater wear takes place on the rake face of the tool where the chip moves over the tool surface. A crater is usually formed at some distance from the cutting edge and it is most frequently observed when cutting steels and other high-melting-point metals at relatively high cutting speeds [**Trent 1979**]. This crater gradually becomes deeper with time and may lead to the breakage of the cutting edge, rendering the tool useless. With the advancement of machining the tools attain crater wear at the rake surface and flank wear (on the major and minor flank of a tool) at the clearance surfaces due to continuous interaction and rubbing with the chips and the work surfaces, respectively [**Dhar et al. 2002**]. Among the abovementioned wears, the principal flank wear is the most important because principal flank wear generally causes an increase in the cutting force and the interfacial temperature, leading normally to dimensional inaccuracy in the work pieces machined and to vibration, which makes the cutting operation less efficient. After all, turning carbide inserts having enough strength, toughness and hot hardness generally fail by gradual wears. In general, wear due to adhesion, diffusion and oxidation are known to occur, but especially abrasion and attrition (adhesion) between the tool and the workpiece, as well as between the tool and the chip formed, for the case of machining of steel using carbide tools [**Ezugwu and Wang 1996; Wang 1997; Ezugwu and Machado 1988**].

2.3 Methods and Effects of MQL in Machining

It is long belief, use of cutting fluids in metal machining produce better surface finish, greater part accuracy, longer tool-life, and improved chip control. It is important to find a way to do machining processes without or with little cutting fluid and, at the same time, promoting long tool life and good workpiece quality. In order to reach this goal, it is necessary to find the suitable cutting conditions and also to develop new tool materials with lower friction coefficient and high heat resistance. Moreover, sometimes, the costs of tools may increase with the use of minimum lubrication, due to the increase of tool wear, even though the overall manufacturing cost may be lower when compared to the costs of using high amount of soluble oil in the processes [**Heisel et al. 1998** and **Kalhöfer 1997**].

The optimization of cutting conditions to make them more suitable for dry cutting is done through the increase of feed and decrease of cutting speed. With this, roughly the same amount of heat is generated, but the area of the tool, which receives this heat, is bigger, making the temperature lower and the amount of chip removed per minute constant (without increasing cutting time). This action may damage the work piece surface finish due to the increase of the feed. Therefore, it is also necessary to increase the tool nose radius in order to keep the surface roughness at the same level [**Klocke and Eisenblätter 1997**].To minimize the use of cutting fluids in machining processes two techniques have become successful. The first one is dry cutting or cutting with no fluid [**Lugscheider et al. 1997** and **Granger**]. For this to be possible without causing a large decrease in tool life and loss of workpiece quality, it is mandatory to have suitable tool materials and cutting conditions. Hard coatings of tool materials, including diamond coating, have been used to accomplish this purpose [**Machado** and **Wallbank 1997; Chiesa et al. 1995** and **Coelho et al. 1995**].

Minimum Quantity of Lubrication (MQL) can be tried to reach the goal of minimizing the amount of cutting fluid in machining process. In abovementioned processes where dry cutting is either not possible or not economical, a second technique, this name is given to the process of pulverizing a very small amount of oil (50-500 ml/h) in a flow of compressed air. Some good results have been obtained with this technique [**Dhar** and **Islam 2005; Dhar et al. 2004; Coelho et al. 1995; Tönshoff** and **Spintig 1994** and **Ferraresi 1974**]. The drilling of aluminum–silicon alloys is a process where dry cutting is impossible [**Derflinger et al. 1999**], due to the high ductility of the workpiece material. Without cooling and lubrication, the chip sticks to the tool and breaks it in a very short time during cutting. **Lugscheider et al. [1997]** used this technique in the reaming process of aluminum alloy (AlSi12) and gray cast iron (GG25) with coated carbide tools and concluded that it caused a reduction of tool wear when compared to the completely dry process and, consequently, an improvement in the surface quality of the holes.

After all, the use of dry machining applications and Minimum Quantity Lubricants (MQL) are continuing to grow due to following reasons:

Continued innovation in cutting tool development involving advanced cutting tool materials and coatings [**Machado** and **Wallbank 1997; Chiesa et al. 1995** and **Coelho et al. 1995**]

High cost of cutting fluids, ranging 7-16% of manufacturing cost, which in many cases is even higher than the tool cost **[Derflinger et al. 1999; Heisel et al. 1998** and **Kalhöfer 1997]**

2.4 Minimal Quantity of Cutting Fluid Application

Only a small amount of lubricant is needed if it is efficiently applied to the cutting zone. This lubricant is completely used and results in almost dry chips. The main characteristic of the 'minimal quantity' application is to substitute all the effects of the coolant lubricant by using jet application to produce effects of equal values. However, it is not possible with minimal quantity application or dry cutting alone all the effects provided by the usual cutting fluid flood-type lubricant. For example, the flushing effect is not supplied and the cooling effect is partially or not at all (with dry cutting) obtained. On the other hand, the results obtained with minimum quantities of cutting fluid application in drilling are excellent compared to the usual flood-type application, **[Popke et al., 1999]**. The paper of Klocke and **[Eisenblätter [1997]** deals with drilling tests using minimum cooling lubrication systems, which are based on atomising the lubricant directly to the cutting zone Small quantities of lubricant, in order of 10–50 ml/h, were mixed with compressed air for an external feeding via a nozzle or for internal feeding via spindle and tool. Internal feed systems with their ability to deliver the mixture very close to the drill–workpiece contact point may achieve very good results in terms of surface finish and tool life.

Wakabayashi et al. [1998], by model experiments, stated that ester supplied onto a rake face of a tool decomposes to carboxylic acid and alcohol and its carboxylic acid forms a chemisorbed film with lubricity. In actual conditions with high machining load, however, existence of this kind of boundary film is uncertain [**Itoigawa et al. 2005**]. Therefore an investigation into the lubrication mechanism of MQL in actual conditions must be essential.

The 'minimal quantity' lubrication is a suitable option for economically and environmentally well-suited production. It combines the functionality of cooling lubrication with an extremely low consumption of lubricant and therefore it has the potential to close the gap between overflow lubrication and dry cutting [**Brinksmeier et al., 1999**].

Machado and Wallbank [1997] conducted experiments on turning medium carbon steel using a Venturi to mix compressed air (the air pressure was of 2.3 bar) with small quantities of a liquid lubricant, water or soluble oil (the mean flow rate was between 3 and 5 ml/min). The mixture was directed onto the rake face of a carbide tool against the chip flow direction. However, even if the obtained results were encouraging, the system needed yet some development to achieve the required effects in terms of cutting forces, temperatures, tool life and surface finish

In order to achieve slow tool wear while maintaining cutting forces/power at reasonable levels minimum quantity lubrication (MQL) concept presents itself as a potential solution for machining.

2.5 Summary of the Review

Enormous efforts are, therefore, being made from the viewpoint of cost, technological and ecological issues to reduce or eliminate the use of cutting fluid or lubricant in metal cutting. In this context, Minimum Quantity Lubrication (MQL) which uses a fine spray of cooling medium like soluble appears to be a promising technique for effective cooling minimizing the problems associated with conventional cutting fluid applications. A literature on machinability of different commercial steel highlights the immense potential of the control of machining temperature and its detrimental effects. All these responses are very important in deciding the overall performance of the tool. At the elevated temperature the cutting tools may undergo plastic deformation and attain rapid tool wear because by adhesive, abrasive, chemical and diffusion wear at the flanks and the crater. The dimensional accuracy and surface integrity of the workpiece also deteriorate due to high temperature.

It is realized that the machining temperature has a critical influence on tool wear and tool life.The application of cutting fluids helps in improving the life and function of cutting tools and in achieving the desired size, finish and shape of the workpiece. But the conventional types and methods of application of cutting fluid have been found to become less effective with the increase in cutting velocity and feed when the cutting fluid cannot properly enter the chip-tool interface to cool and lubricate due to bulk plastic contact of the chip with the tool rake surface. Further the use of conventional cutting fluid generally causes economy of tools and is not environment friendly as well.

However, the performance and effectiveness of MQL by water–soluble cutting oil on machining medium carbon steel has been investigated over both dry and wet machining in terms of tool wear, surface roughness and dimensional deviation. MQL will only be acceptable on condition that the main tasks of coolants in machining processes can be successfully replaced.

2.6 Objectives of the Present Work

It is very straightforward from the eforeseid literature survey that MQL can control remarkably the cutting temperature as compared to dry and wet machining, which cause of several problems limiting productivity, quality and hence machinability in terms of economy.

The main objective of the present work is to make an experimental investigation on the roles of Minimum Quantity Lubricant (MQL) by water-soluble cutting fluid on the machinability characteristics in respect of

i. tool wear, pattern and extent of tool wear
ii. surface roughness
iii. dimensional deviation

in turning medium carbon steel by the industrially used coated carbide tool (SNMM 120408) at fixed cutting velocity and feed rate.

The scopes of the present work are

(a) Design and fabrication of a suitable nozzle for MQL jet so that it can cover entire cutting zone avoiding bulk cooling and

(b) Analysis of data by

   i. measuring tool wears (principal flank wear and auxiliary flank wear) under optical microscope (Carl Zeiss, Germany) of 10 μm least count

   ii. monitoring pattern and extent of tool wear under Scanning Electronic Microscope (SEM)

   iii. measuring surface roughness with the aid of a Tally surf (Surtronic 3^+) roughness checker.

   iv. estimating dimensional deviation during a complete pass with a first hand tool and a precision dial gauge of 10 μm least count.

Chapter-3

Design and Fabrication of MQL Applicator

3.1 Introduction

To produce better surface finish, greater part accuracy and improved chip control as well as longer tool-life, cutting fluids in machining metal has long been using a reliable method. In machining processes, two techniques have been successfully prevailed over minimizing the use of cutting fluids. The first one is Minimum Quantity of Lubrication (MQL), which can be attempted to reach the goal of minimizing the amount of cutting fluid as well as fluid related problems in machining process. The other technique is dry cutting or cutting with no fluid. But, in those two processes, dry cutting is whether not possible or not economical.

Jet application using coolant lubricant produces effects that are just surrogated by the application of "minimal quantity" lubricant of liquid in the same, in some cases more value. Only a small amount of lubricant is needed if it is efficiently applied to the cutting zone. This lubricant is completely used and results in almost dry chips. However, all the effects provided by the usual cutting fluid flood-type lubricant are not possible with minimal quantity application or dry cutting alone. It combines the functionality of cooling lubrication with an extremely low consumption of lubricant and therefore it has the potential to close the gap between overflow lubrication and dry cutting. Besides, the 'minimal quantity' lubrication is a suitable and proven alternative for economically and environmentally compatible production.

The MQL system needs to be properly designed for achieving extensive technological and economical benefits as well as environment benign,

The following important factors should be considered:

i) MQL jet should reach as close as possible to the actual cutting hot zones for effective cooling.

ii) Pin-pointed impingement and only during chip formation require minimum use of cutting fluid.

iii) to avoid bulk cooling of the tool and

iv) job that is responsible for adverse changes in metal shape.

3.2 Design and Fabrication of the MQL Applicator

Impact at high speed and at high pressure through the nozzle at the hot cutting zone is required for MQL. Considering the conditions needed for the present research work and uninterrupted supply of MQL at constant pressure about 6.5 bars over a reasonably long cut; a MQL applicator has been designed, fabricated and used. The photographic view of the MQL applicator is shown in Fig 3 1.

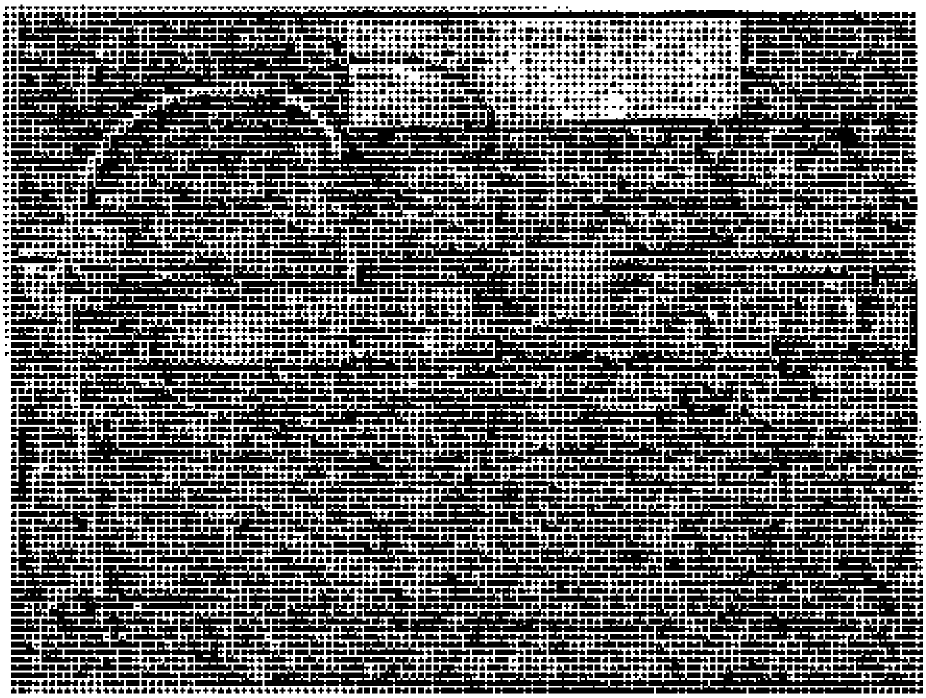

Fig 3.1 Photographic view of the MQL applicator

The use of Minimum Quantity Lubrication (MQL) indicates a little amount of cutting fluids flow rate of typically 50 to 500 ml/hour-which is about five to six orders of magnitude less than the amount used commonly in flood cooling condition, in which at least 600 liters of fluid can be supplied per hour.

There are two major components of the MQL system has: MQL applicator and Compressor. To contain the water soluble cutting fluid selected for a particular machining the fluid chamber is only used to contain. It has an inlet port and an outlet port at the top and at the bottom respectively. It is connected to the compressor by a flexible pipe through the inlet port to keep the fluid inside chamber under a constant pressure of 6.5 bars. However, based on the research requirement, fluid chamber has been designed with capacity of one litre (1000 ml) so as to able to supply the water soluble cutting fluid continuously for at least four hours during machining at a flow rate of 100 ml/hr. It is required to maintain the flow of cutting fluid into the mixing chamber at constant rate over a long period of time during machining. Compressor used in this system acts as air supply unit and is able to develop a maximum pressure of 6.5 bars.

Nozzle, one of the most important parts of the MQL system, in which water soluble cutting fluid from the chamber enters the mixing chamber of the nozzle by a long flexible pipe through the central tube. Compressed air from the compressor enters the mixing chamber through the other tube. In the mixing chamber the Water soluble cutting fluid comes out through four holes and air comes through six holes. Both water soluble fluid and air comes out at a constant rate and mix together. This mixture passes through a slender tube called nozzle. The tip of the tube (0.50 mm diameter) is attached with an arrangement to tool holder so that the mixture of water soluble cutting fluid and air fall on the tip of the insert which is attached to the tool holder.

3.3 Design and Fabrication of the Nozzle

To control MQL rate and covering area of the cutting zone, spray pattern type nozzle has been designed. The nozzle developed and used is oriented along the auxiliary cutting edge of the tool, is shown in Fig.3.2

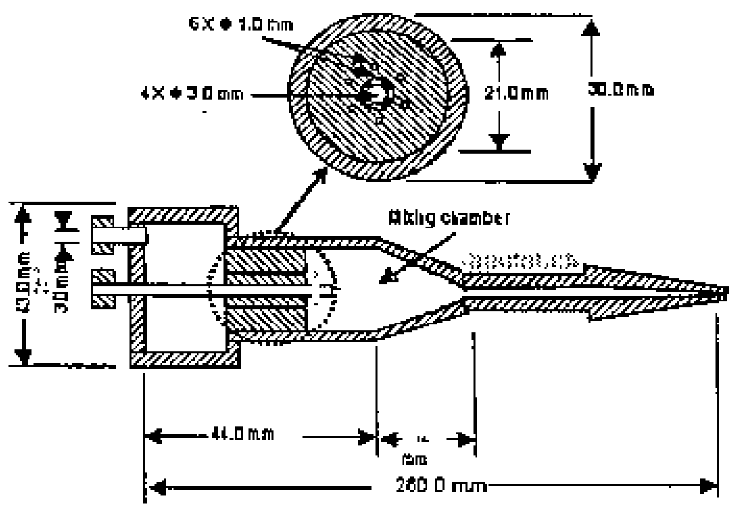

Fig. 3.2 Schematic view of the nozzle with mixing chamber

There are three chambers in nozzle. The first one is air chamber, the second or middle part is passage way by which air and oil can flow, the last part is mixing chamber. All the three parts are connected by screw and thread fastening. From compressor high pressure air come into the air chamber and pass away through six Φ 1.0mm holes of middle part. On the other hand water soluble cutting fluid come from cutting fluid and pass through Φ3.0mm tube and come out through four Φ1mm holes at the end of middle part and mix with high pressure air in the mixing chamber and finally pass through Φ0.5mm nozzle tip.

The nozzle having bore diameter reduction ratio, i.e. inlet diameter to outlet diameter, 6:1 is attached to the tool post and is connected with flexible pipe to supply MQL in the form of jet to the chip-tool and work-tool interfaces of the cutting zone along auxiliary cutting edge The expected result of this arrangement is effective cooling with economical MQL dispensing. The construction and setting of the nozzle tips have been made primarily aiming: **Firstly**, high speed MQL jet reaching quite close to the chip-tool contact zone. **Secondly**, simple and low cost. **Thirdly**, less interference with the flowing chips.

3.4 Working Principle of MQL System

The fluid chamber is connected at the nozzle with small diameter flexible tube. This tube is passed through a roller-type flow controller to permit a little amount of fluid to flow under high pressure. A compressor is used to supply air at a high-pressure of 6-8 bars. The compressed air entering into the inlet port creates pressure to cause the fluid to flow continuously to the mixing chamber of the nozzle through controller at a constant rate. The air and the water soluble cutting fluid are mixed in the mixing chamber of the nozzle so that the mixture of cutting fluid and air is having an effect at a high velocity through the nozzle at the chip-tool interface. The schematic views of the nozzle with mixing chamber is shown in Fig 3.2 and. High velocity but thin stream of MQL is to be injected targeting the principal flank along the auxiliary cutting edge of the insert, as a result coolant reach as close to work-tool and chip-tool interfaces as possible during experimentation.

Chapter-4

Experimental Investigations

4.1 Introduction

The temperature becomes more vigorous when feed and cutting velocity are increased for higher MRR and the work materials are relatively difficult to machine for their higher hardenability, strength and lesser thermal conductivity. During machining the generation of high cutting temperature not only reduces tool life but also impairs the product quality. Cutting fluids are widely used to reduce the cutting temperature. The use of conventional methods and type of cutting fluids, which are mostly oil based are associated with some problems:

i) additional floor space, storage, pumping system, recycling and disposal system are needed.

ii) uncleanliness causes inconvenience to of the working area.

iii) desired cooling and lubrication is incompetence .

To achieve substantial technological and economical benefits in terms of environment friendliness, MQL is better way. Proper application of MQL may play vital role in providing not only environment friendliness but also some techno-economical benefits that have already been experienced through prior research.

The following factors regarding the MQL are important from the subject point of view:

i) properly designed.

ii) Minimum consumption of cutting fluid.

iii) pin-pointed impingement

iv) MQL jet reach close to the cutting hot zones for effective cooling

v) to protect adverse metallurgical changes keeping away from bulk cooling of the job and the tool.

4.2 Experimental Procedure and Result

It has already been recognized that MQL has positive part on environment friendliness as well as techno-economical benefit. To evaluate and explore the job of MQL on machinability distinctiveness of a tool-work combination, frequently used in machining industries, mostly in terms of, surface finish, dimensional deviation and tool wear, which manage product quality, productivity, and overall economy is endeavor of the present work.

Straight turning of medium carbon steel at fixed cutting velocity (Vc) and feed (So) under dry, wet and MQL conditions have been carried out in a rigid and reasonably powerful lathe (15 hp/11kW, France) by standard coated carbide insert (SNMM 120408, Sandvik). The strength, hardness, compositions and industrial use of this steel are given below Table 4.1

Table 4.1 Characteristics of the used steel

Material	BHN	Chemical composition (wt %)	Applications
Medium carbon steel	180	C - 0.410 Mn - 0.700 P - 0 040 S - 0.050	• Shafts & crank shafts • Automobile axles • Spindles • Lightly stressed gears

How closely the MQL jet can reach the work-tool interfaces and the chip-tool where, apart from the primary shear zone, heat is generated, cooling effectiveness and other related benefits count on that matter.

One of the most important factors that is reasonably expected to play important role on cooling effectiveness is the tool geometry. Remembering this standard tool geometry namely SNMM 120408 (Sandvik) has been undertaken for the present investigation. The inserts were clamped in a PSBNR 2525 M12 type sandvik tool holder.

The nozzle tip orientation regarding the cutting insert has been settled after a few trial and fixing an inclined metal stripe to the insert holder and nozzle tip attaching on it. The thin but high velocity stream of MQL was heading for along the auxiliary cutting edge of the insert, so that the coolant reaches as close to the chip-tool and the work-tool interfaces as possible and cools the above mentioned interfaces and both the principal and auxiliary flanks effectively as well.

The machinability characteristics of the steel specimens under dry, wet and minimum quantity lubrication (MQL) conditions have been studied and evaluated for assessing the machining responses that are indicated in Table 4.2.

Table-4.2 Investigation of machining responses

Work material:	**Medium carbon steel (φ92 X 700 mm)**		
Cutting Insert	**Coated carbide (SNMM 120408)**		
Investigations made on	**Working condition**		
	Dry	**Wet**	**MQL**
Tool wear	✓	✓	✓
Surface roughness	✓	✓	✓
Dimensional deviation	✓	✓	✓

The conditions under which the machining tests have been carried out are in a few words given in Table 4.3.

Table 4.3 Experimental conditions

Machine tool	: Lathe Machine (France), 15 hp
Work material	: Medium carbon steel (φ 92 X 700 mm)
Cutting tool (insert)	
Cutting insert	: Coated Carbide, Sandvik
	
	SNMM 120408
Tool holder	: PSBNR 2525M12(ISO specification)
Working tool geometry	: Inclination angle : -6°
	Orthogonal rake angle : -6°
	Orthogonal clearance angle : 6°
	Auxiliary cutting edge angle : 15°
	Principal cutting edge angle : 75°
	Nose radius : 0. 8 mm
Process parameters	
Cutting velocity, V_c	: 233 m/min
Feed rate, S_o	: 0.18 mm/rev
Depth of cut, t	: 1.0 mm
MQL supply	: Air: 6.5 bar, Lubricant: Water-soluble cutting fluid, 100 ml/h (through external nozzle).
Condition	: Dry, Wet and Minimum Quantity Lubrication (MQL).

It is commonly believed that application of cutting fluid during machining reduce cutting temperature and increase tool life but it is not always true.**[Dhar et al 2004; Paul et al. 2000 and Seah et al. 1995]** reported that use of conventional cutting fluids (wet machining) does not provide the desired purpose in machining steels by carbides, rather reduces tool life and brittle fracture may often cause premature failure of the insert

The depth of cut (t) on cutting temperature, saving of work material and avoidance of dominating effect of nose radius on cutting temperature has less significant role. In order to serve adequately the present purpose the depth of cut was kept fixed to only 1.0 mm.

Sophisticated and reliable equipments and techniques have been engaged to monitor and study the machining responses.

4.3 Cutting Tool Wear and Condition

Life of the cutting tools considerably affected productivity and economy of manufacturing system. Turning carbide inserts having enough toughness; hot hardness and strength generally fail by gradual wears. Cutting tools may fail by plastic deformation or gradual wear, brittle fracture.

Gradual wear is generally assessed the tool life in any case for R&D work, which ultimately cause systematic fail. Progress of machining may induce vibration with aggravates cutting forces and temperature by the average value of the principal flank wear (V_B). The pattern and extent of wear (V_S) of the auxiliary flank affects surface finish and dimensional accuracy of the machined parts For given tool-work pairs, increase of tool wear is considerable manipulated by the temperature and nature of connections of the tool-work interfaces, which again maintained by the machining conditions.

To reduce the rate of growth of flank wear (V_B), attempts should be made in all possible ways without much give up in Material Removal Rate.

The cutting insert was pullout at regular intervals and then the relevant features like, V_B, V_S etc., were measured under metallurgical microscope (Carl Zeiss, 351396, Germany) fitted with micrometer of least count 1µm after machining under each condition. Sufficient wear the pattern and extent of wear of each tool was examined under Scanning Electron Microscope (Hitachi, S-2600N SEM, Japan) and the photographs are taken for onward comparative study at the end of machining.

Fig.4.1 clearly shows that machining is done with the help of MQL Water soluble cutting fluid, the average principal flank wear, V_B decreased substantially. Flank wear occurs mainly by micro chipping and abrasion and increase with in V_c and S_o adhesion and diffusion. Due to intimate contact with the work surface at elevated temperature crater wear of carbide tools while machining steels particularly at higher V_c and S_o occur by adhesion and diffusion as well as post abrasion also come into picture.

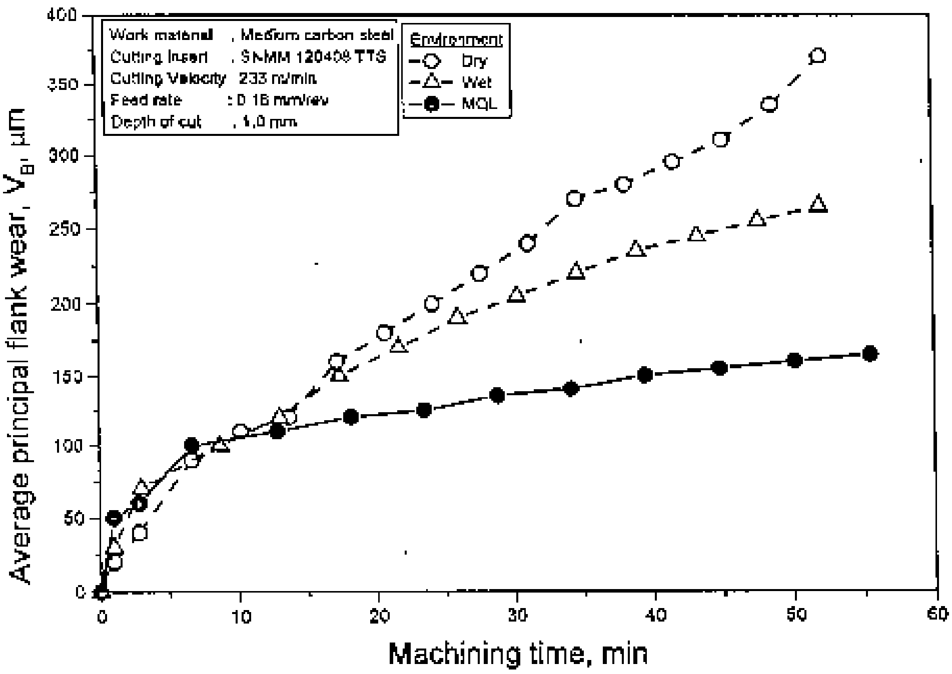

Fig.4.1 Growth of average principal flank wear with machining time under **dry**, **wet** and **MQL** conditions

Substantial reduction in the cutting temperature by MQL by water-soluble cutting fluide mainly the jet impinged along the auxiliary cutting edge, which helped in reducing abrasion wear by retaining tool hardness and also adhesion and diffusion types of wear which are highly responsive to temperature is the reason to decline V_B reasonably. Such reduction in rate of growth of flank wear in the tool, the tool life would be much higher if MQL by water soluble oil is appropriately applied. It appears from Fig.4.2 that auxiliary flank wear (V_S) has also decreased considerably due to proper temperature control under MQL by water soluble cutting fluid. Auxiliary flank wear (V_S), even if occurs less intensively, also plays significant role in machining by worsening dimensional accuracy and roughness of the finished surface.

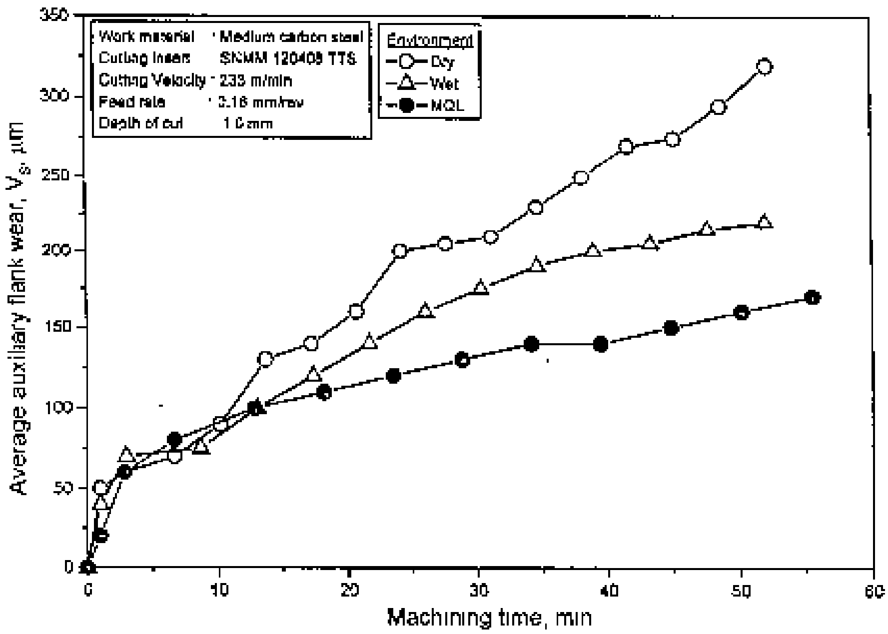

Fig.4.2 Growth of average auxiliary flank wear with machining time under **dry**, **wet** and **MQL** conditions

The positive effect of MQL by water-soluble cutting fluid on flank wear of insert has been briefly shown in Fig.4.4 after 52 minutes of machining the insert attained an average flank wear of around 370 µm under dry, 265 µm under wet machining whereas MQL by water-soluble cutting fluid reduced flank wear to 165 µm only, whereas the insert attained an average auxiliary flank wear of round 320 µm under dry, 220 µm under wet machining and 170 µm under MQL by water-soluble cutting fluid.

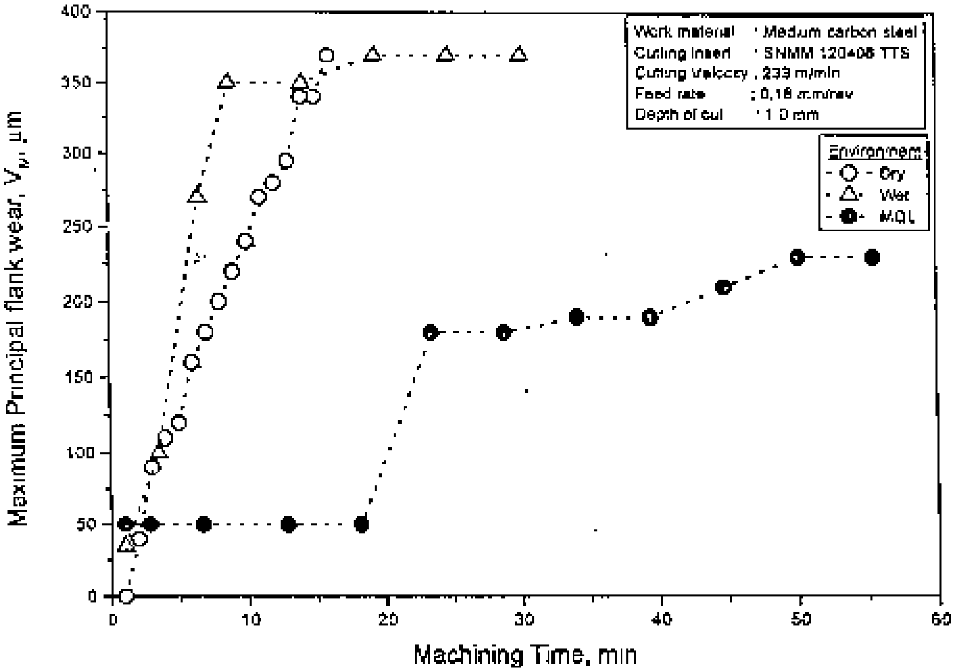

Fig.4.3 Growth of maximum flank wear, V_M with machining time under **dry**, **wet** and **MQL** conditions

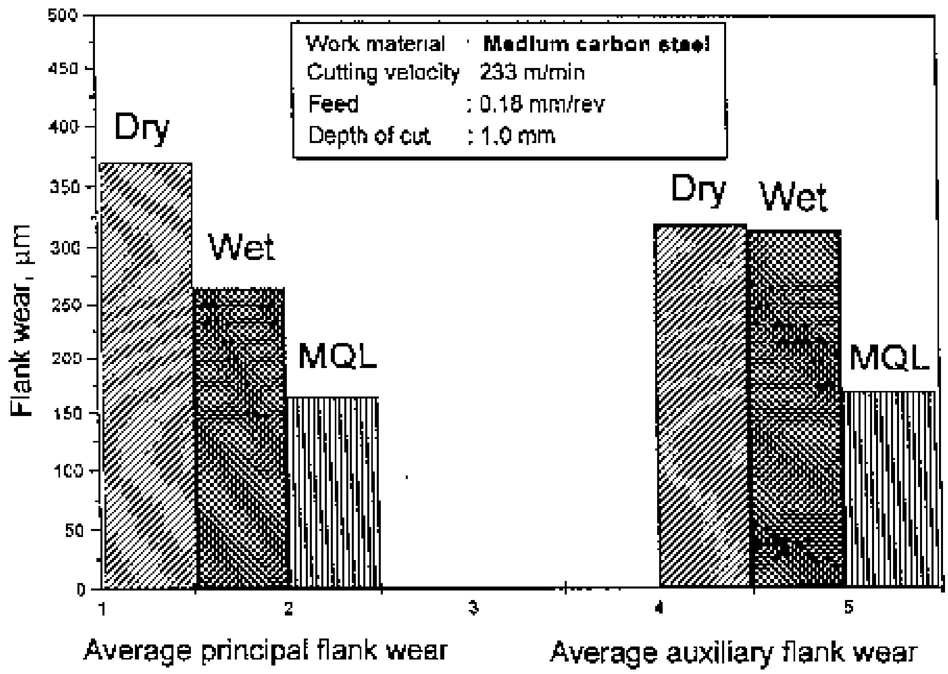

Fig. 4.4 Flank wear developed in insert after machining steel for 52 minutes under **dry**, **wet** and **MQL** conditions.

After being used for machining the medium carbon steel over reasonably long period, the pattern and extent of wear developed at the different surfaces of the tool tips that have been observed under SEM to see the actual effects of different environments on wear of the coated carbide insert of present configuration. The principal and auxiliary flank wear of the worn out insert after about 52 minutes of machining of the steel under dry, wet and MQL conditions SEM views have been shown in Fig. 4.5 and Fig. 4.6 respectively

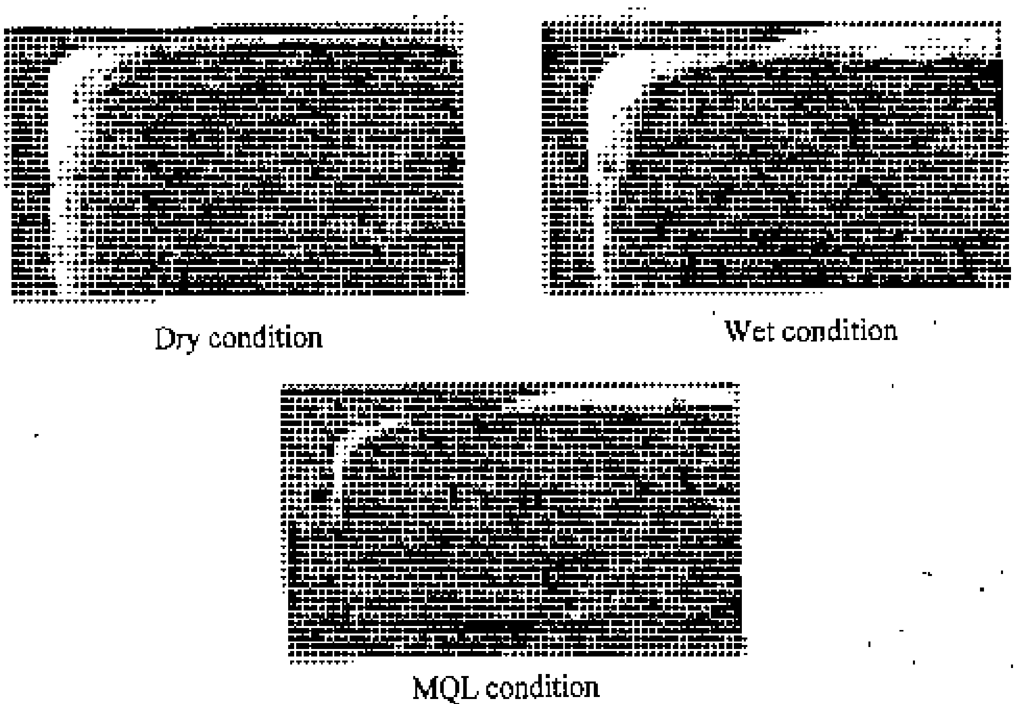

Fig.4.5SEM views of principal flank wear of the worn out insert after machining 52 minutes under **dry, wet** and **MQL** conditions.

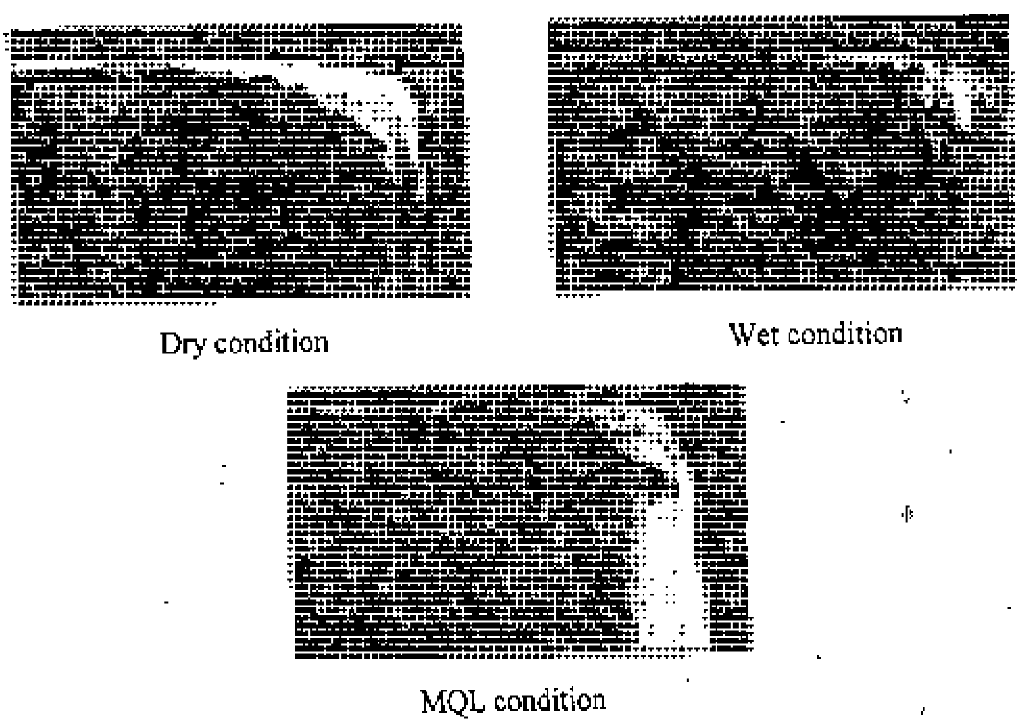

Fig.4.6SEM views of auxiliary flank wear of the worn out insert after machining 52 minutes under **dry**, **wet** and **MQL** conditions.

4.4 Surface Roughness

Surface roughness is an important index of machinability, which is substantially influenced by the machining environment for given tool-work pair and speed-feed combinations The surface finish was measured respectively by a Talysurf (Surtronic 3+ Roughness Checker, Taylor Hobson, UK) using a sampling length of 0 8 mm after machining the steel medium carbon bar by the coated carbide insert, at V_c-S_o combinations under dry, wet and MQL conditions, The Photographic view of the surface roughness technique for measuring surface roughness is shown in Fig.4.7

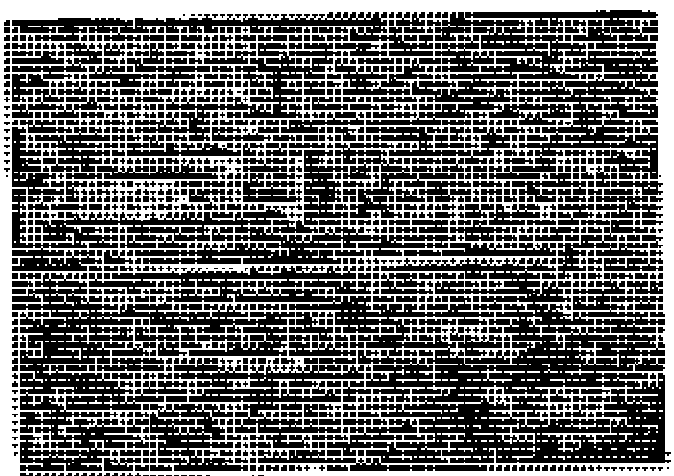

Fig. 4.7 Photographic view of the surface roughness measuring technique

Quality of the product for a given material is generally assessed by dimensional and form accuracy and surface integrity of the product regarding surface roughness, residual stresses and surface and subsurface micro cracks, oxidation, corrosion. The performance and service life of any machined part are governed largely by product quality

Surface roughness has been measured after a few seconds of machining with sharp tool at the same time recording the chip-tool interface temperature. The pictorial view of the surface roughness technique for measuring surface roughness is shown in Fig.4.7 After 52 seconds of machining of steel by the coated carbide insert (SNMM 120408, Sandvick) at V_c-S_o combinations under dry, wet and MQL conditions the surface roughness achieved are shown in Fig.4.8.

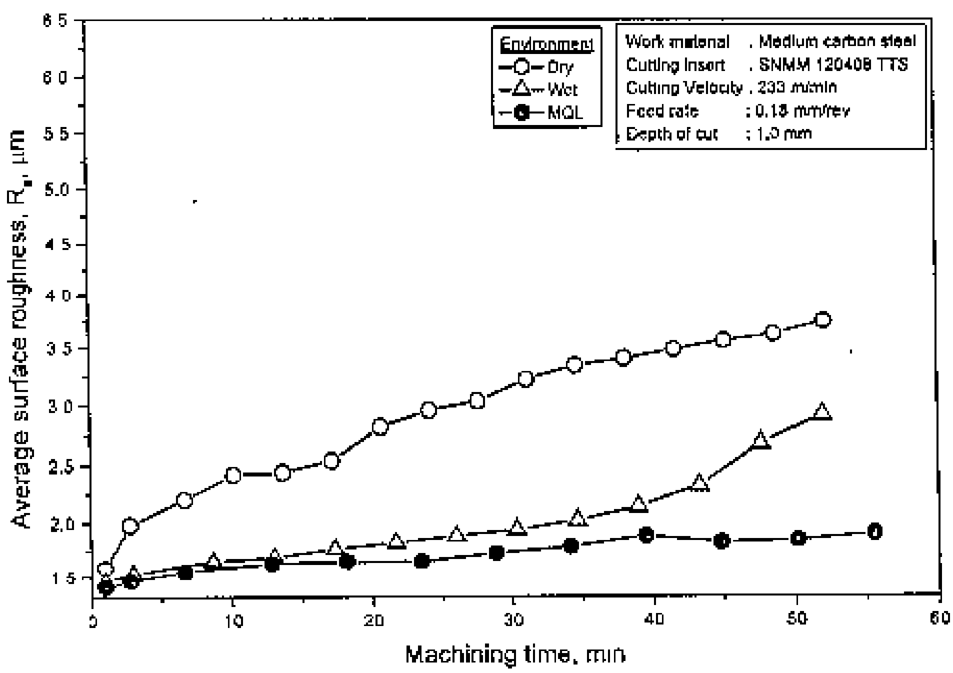

Fig.4.8 Variation in surface roughness with progress of turning steel by coated carbide insert under **dry, wet** and **MQL** conditions.

4.5 Dimensional Deviation

Dimensional accuracy also governs the performance and service life of the product. The quality of any machined product of given material is generally assessed by dimensional accuracy. In the present study, dimensional accuracy under dry, wet and MQL machining has been considered for judgment of product quality.

Dimensional accuracy often affected pperformance and service life of the machined/ground component.

Development of Dimensional deviation in continuous machining processes like turning, particularly of ductile metals is caused by -

i vibration in the machining system

ii. improper machine set-up, tool and work

Dimensional deviation of the machined work piece was measured by fitting a dial gauge of least count 10 µm on the carriage of the machine tool under a complete pass of machining. During machining gauge reading was taken in 10 mm interval and plotted shown in figure 4.9.

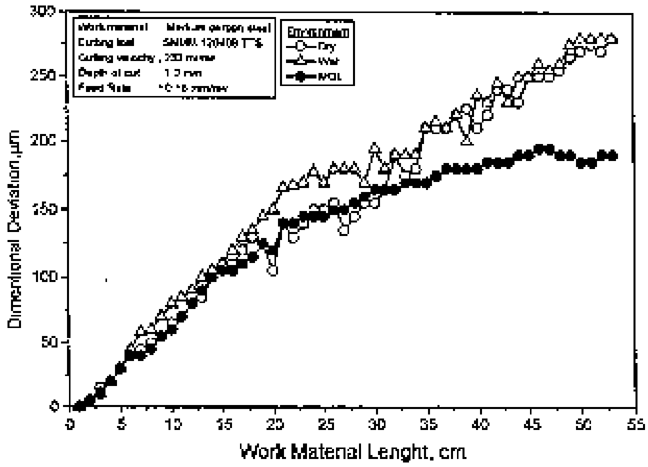

Fig.4.9 Variation in dimensional deviation with progress of turning steel by coated carbide insert under **dry**, **wet** and **MQL** conditions.

Chapter-5

Discussion on Experimental Results

5.1 Cutting Tool Wear and Condition

Tool wear initially starts with a reasonably faster rate due to what is called break-in wear caused by attrition and micro-chipping at the sharp cutting edges. Depending upon the tool-work materials and machining condition, the cutting tools in conventional machining generally failed by gradual wear by abrasion, adhesion, diffusion, chemical erosion, galvanic action etc., for example, continuous chip formation processes such as turning.

In the present investigations with the tool and work material and the machining conditions undertaken, the tool failure mode has been mostly gradual wear. Mechanical breakage and plastic deformation under adverse machining conditions caused by intensive pressure and temperature and/or dynamic loading at the tool tips particularly if the tool material lacks hot-hardness, fracture toughness and strength may also often fail prematurely, randomly and catastrophically of the cutting tools. The principal flank wear (V_B) is the most important because it raises the cutting forces and the related problems, among the abovementioned wears. Wearing is the main reason to fail the life of carbide tool. The life of coated carbide tool mostly assessed by the actual machining time after which the average value (V_B) of its principal flank wear reaches a limiting value, like 0.3 mm. The rate of growth of flank wear (V_B) in all possible ways attempts are to be made to reduce without decreasing in Material Removal Rate.

The growths of average principal flank wear, V_B, on the main cutting edge under dry and MQL by Water soluble cutting fluid conditions have been shown in Fig.4.1. The major parameter to find out expiry of tool life, The gradual growth of average principal flank wear, V_B, observed under the dry, wet and MQL conditions point out steady machining without any premature tool failure by chipping, fracturing etc. ascertaining proper choice of field of process parameters. Fig.4.1 also clearly shows that average principal flank wear, V_B mainly its rate of growth decreased by MQL by Water soluble cutting fluid. It is obvious that reduction in the flank temperature by MQL causes reduction in V_B which helped in reducing abrasion wear by retaining tool hardness and also adhesion and diffusion types of wear which are highly responsive to temperature. If MQL is properly applied in such reduction rate of growth of flank wear the tool life would be much higher.

The surface finish on the job as well as dimensional accuracy is governed by another important tool wear criteria are average auxiliary flank wear, V_S. Irregular and higher auxiliary flank wear leads to poor dimensional inaccuracy and surface finish.

For all the trials undertaken the growth of average auxiliary flank wear, V_S has been depicted in Fig.4.2 The nature of growth of average auxiliary flank wear, V_S matches with that of V_B expectedly. It appears from Fig.4.2 that auxiliary flank wear (V_S) has also decreased during MQL machining. The amount of both average principal flank wear and auxiliary flank wear after machining for 52 minutes and depicts favorable role of MQL has been clearly shown in Fig.4.4. Better surface finish and dimensional accuracy expected to be provided by MQL

After being used for machining the medium carbon steel over practically long period, the pattern and extent of wear developed at the different surfaces of the tool tips that have been observed under SEM to see the actual effects at different environments on wear of the coated carbide insert of SNMM configuration. The SEM views of principal and auxiliary flank wear of the worn out insert after about 52 minutes of machining of medium carbon steel under dry, wet and MQL conditions have been clearly shown in Fig.4.5 and Fig.4.6 respectively.

There have also been some indications of adhesive wear in the insert under dry, wet and MQL condition. Abrasive scratch marks appeared in the flanks. Severe groove wear at the flank surfaces were found in insert under dry and wet conditions. Under dry machining some plastic deformation and micro chipping to occur were found. MQL by Water soluble cutting fluid almost reduced the growth of groove wear on the main cutting edge as well as auxiliary cutting edges effectively by controlling temperature. Moreover, reduced average principal flank wear and average auxiliary flank wear under MQL by Water soluble cutting fluid condition have been clearly shown in the figure.

5.2 Surface Roughness

Development of surface roughness in continuous machining processes like turning, particularly of ductile metals, the major causes are:

i. vibration in the machining system
ii built-up edge formation
iii. on the finished surface, regular feed marks left by the tool- tip
iv. due to chipping, fracturing and wear at the tool-tip irregular deformation of the auxiliary cutting edge .

However, it is evident that MQL by Water soluble cutting fluid improves surface finish depending upon the work-tool materials and mainly through controlling the deterioration of the auxiliary cutting edge by abrasion, chipping and built-up edge formation.

As MQL by Water soluble cutting fluid reduced average auxiliary flank wear and produced no notch wear on auxiliary cutting edge, surface roughness also grew very slowly under MQL by Water soluble cutting fluid conditions. The variation in surface roughness observed with progress of machining of medium carbon steel by the SNMM insert at a particular set of cutting velocity, V_c, feed rate, S_o and depth of cut, t under dry, wet and MQL by Water soluble cutting fluid conditions have been shown in Fig.4.7

Conventionally applied cutting fluid did not reduce tool wear compared to dry machining. But the surface roughness deteriorated significantly under wet machining compared to dry, which may possible be attributed to electrochemical interaction between insert and work piece.

It appears from Fig.4.8 that surface roughness grows quite fast under dry machining due to more intensive temperature and stresses at the tool-tips. MQL by Water soluble cutting fluid appeared to be effective in reducing surface roughness.

5.3 Dimensional Deviation

Dimensional deviation is another index of surface quality. With the gradual increase in average auxiliary flank wear and lack of rigidity of the machine tool surface roughness inherently increases with machining time. Rapid wear on flanks due to high heat generation, friction between the tool and the chip worsen the condition of tool tip and tool tip can not retain its sharpness. The consequence of such increment in tool wear leads to higher surface roughness and deviate the work piece dimensionally from its required dimension. Fig. 4.9 clearly depicts that deviation is decreased under MQL condition than dry and wet conditions.

Chapter-6

Conclusions

The present experimental investigation based on the results under dry, wet and MQL by water soluble cutting fluid condition, the following conclusions can be summarized:

i. Flood cooling by soluble oil could not control the cutting temperature noticeably and its effectiveness decreased further with the increase in cutting velocity and feed rate. MQL by water soluble cutting fluid provided significant improvements in respect of surface finish due to reduction in the average chip tool interface temperature.

ii. Due. to reduction of wear and damage at the tool-tip by the application of MQL by water soluble cutting fluid, surface finishes also improved.

iii. Minimum quantity lubrication (MQL) reduces deep grooving, which is very detrimental and may cause premature and catastrophic failure of the cutting tools.

iv. The reduction in flank wear would enable both notable improvement in tool life or enhancement of productivity (MRR) allowing higher cutting velocity and feed. The considerable contribution of MQL jet in machining the steel by the coated carbide insert is to reduce flank wear. Such reduction in tool wear might have been possible for retardation of abrasion, decrease or prevention of adhesion and diffusion type thermal sensitivity wear at the flanks and reduction of built-up edge formation which accelerates wear at the cutting edges by chipping and flaking.

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