An Experimental Study of Effect of Vegetable Oil as a Cutting Fluid on Tool Wear and Product Quality in Turning Different Types of Steel

A Project Thesis

By

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DEPARTMENT OF INDUSTRIAL & PRODUCTION ENGINEERING
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DHAKA, BANGLADESH

September, 2006

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Submitted to the Department of Industrial & Production Engineering, Bangladesh University of Engineering & Technology, Dhaka, in partial fulfillment of the requirements for the degree of **Master of Industrial & Production Engineering** on September, 2006.

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The project titled **An Experimental Study of Effects of Vegetable Oil as a Cutting Fluid on Tool Wear and Product Quality in Turning Different Types of Steel**, submitted by Md. Yasir Arafat, Student No. 040408004 F, Session- April 2004, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **Master of Industrial & Production Engineering** on September, 2006 .

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Declaration

It is hereby declared that this thesis or any part of its has not been submitted elsewhere for the award of any degree or diploma.

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Abstrac

For higher productivity in manufacturing by machining, high material removal rate is essential. High production machining with high cutting velocity, feed and depth generates a large amount of heat and high cutting temperature at tool-workpiece contact zone. Such high cutting temperature accelerates the growth of tool wear and enhances the chances of premature failure of the tool by plastic deformation and also affect the surface Integrity. Suitable cutting fluid is needed to employ to reduce the temperature through cooling and lubrication in the cutting zone. 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. Minimum Quantity Lubrication (MQL) by agents like soluble and vegetable oils appears to be a promising technique for effective cooling without the problems associated with conventional cutting fluid applications. In this regard the proposed research work will be carried out with a view to study the effects of vegetable oil as a cutting fluid by minimum quantity lubrication (MQL) by on the cutting performance specially tool wear and surface roughness of AISI 1040 and AISI 9310 steel, as compared to completely dry machining. It is found from previous researches that flood cooling on steel is not effective even have adverse result. MQL machining vegetable oil performed excellent performance due to reduction in tool wear, which enhanced the tool life, dimensional accuracy and surface quality. Furthermore, it provides environment friendliness and improves the machinability characteristics.

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Chapter-1

Introduction

Productivity, product quality and overall economy are the major concem in any type of manufacturing. For higher productivity in manufacturing by machining, high material removal rate is essential. For better product quality and overall economy, cutting tools should have high stability and long life. High production machining with high cutting velocity, feed and depth generates a large amount of heat and high cutting temperature at tool-workpiece contact zone. Such high cutting temperature accelerates the growth of tool wear and also enhances the chances 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.

Turning is a machining process of material removal in which the loss of material is caused by affecting a relative motion between tool and workpiece. Due to removal of material the form of chips, new surfaces are cleaved from the workpiece accompanied by a large consumption of energy. The mechanical energy necessary for the machining operation is transformed into heat, leading to conditions of high pressure, high temperatures and severe thermal and frictional conditions at the tool-chip interface. The greater the energy consumption, the more severe are the thermal/frictional conditions, consequently making tile metal cutting process more and more inefficient in terms of tool life, dimensional accuracy and material removal rate.

Tool life is a function of tool wear. Tool wear is an important factor which affects productivity, manufacturing efficiency and overall economy. It is generally recognized that the cost of tool replacement represents a significant proportion of the total manufacturing cost. A sizeable reduction in the total operating cost to the manufacturing industry could be achieved if cutting tools could be used for a longer period of time before being replaced; productivity could also be increased, as less time would be spent setting up these tools when they were replaced.

Tool-wear estimates and the corresponding economic analysis are among the most critical areas in process planning and machining optimization. When machining with flat-faced tools, either flank wear (V_B) or crater wear (KT) has often been used as a measure for tool-wear/tool-life. Tool-wear/tool-life is significantly affected by the combined effects of cutting conditions and characteristics of work-piece and tools.

In turning, tool wear depends on the following parameters **[Trent, 1984]:**

i. the material of the tool
ii. tool geometry
iii. the material of the workpiece part
iv. cutting conditions

v. cutting fluid or coolant

Surface finish is a function of tool wear for continuous cutting. The major causes behind development of surface roughness in continuous machining processes like turning, particularly of ductile metals are regular feed marks left by the tool tip on the finished surface, tool flank and nose wear and vibration while machining.

The machining temperature and its detrimental effects can be reduced by proper selection of process parameters and geometry of the cutting tools, proper selection and application of cutting fluid and using heat and wear resistant cutting tool materials like diamond, CBN, carbides, coated carbides and high performance ceramics. Diamond, and CBN 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.

Cutting fluid play a significant role in improving lubrication as well as minimising temperature at the tool–chip and tool–workpiece interfaces, consequently, minimising seizure during machining. It also cleans cutting zone. 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. Because the cutting do not readily access the tool–workpiece and tool–chip interfaces. Besides that, often in high production machining the cutting fluid may cause premature failure of the cutting tool by fracturing due to close curling of the chips and thermal shocks. For which application of high cooling type water base cutting fluids are generally avoided in machining steels by brittle type cutting tools like carbides and ceramics.

Cutting fluid has adverse effects of polluting the working environment and biological hazards to the operators as well as the environment. The modern industries are, therefore, looking for possible means of dry, clean, neat and pollution free machining and grinding. Minimum Quantity Lubrication (MQL) by agents like soluble and vegetable oils appears to be a promising technique for effective cooling without the problems associated with conventional cutting fluid applications. But it is also essential to be assured that productivity and overall economy are not affected while deriving the environmental benefits of Minimum Quantity Lubrication (MQL). Rather it is necessary to explore the possible technological benefits of such Minimum Quantity Lubrication (MQL) and optimise it for maximum overall socio-economic benefits.

Chapter-2

Literature Review

Intensive research and investigations have been done in different parts of the world on machinability of different materials mainly in surface integrity and tool wear and life of cutting tool with and without (dry machining) using cutting fluid. A brief review of some of the interesting and important contributions in the closely related areas is presented in this section .

2.1 Tool wear

Tool wear in machining is defined as the amount of volume loss of tool material on the contact surface due to the interactions between the tool and workpiece. Like most wear applications, tool wear has proved difficult to understand and predict. However, most tool wear can be described by a few mechanisms, which include: abrasion, adhesion, chemical reaction, plastic deformation, and fracture. Common types of tool wear in turning:

i. Flank wear

ii. Crater wear

iii. Notch wear

iv. Edge chipping (or micro-chipping)

v. Built-up edge (BUE)

vi. Catastrophic edge breakage

vii. others

But major forms of wear are commonly observed on a cutting tool: flank wear and crater wear **[Trent , 1983]** .This is illustrated in Fig-1. Flank wear occurs on the relief face of the cutting tool and is generally attributed to the rubbing of the tool along the machined surface and high temperatures causing abrasive and/or adhesive wear, thus affecting tool materials properties as well as work piece surface. Abrasion, diffusion and adhesion are the main wear mechanisms in flank wear. Flank wear generally leads normally to dimensional inaccuracy in the workpieces machined and to vibration which makes the cutting operation less efficient.

The flow of the chip on the tool rake face often causes crater wear. Indeed, the tool–chip contact occurs under extreme conditions (high temperature and pressure, intense friction, significant sliding velocity, etc. ..). Moreover, the concentration gradient of chemical species between tool and workpiece material is often very important. This supports the activation of diffusion process and particles move toward areas of low concentration. Atoms diffusing from the tool into the chip are finally carried away by the flow of the workmaterial along the contact surface. The material transfer then leads to the formation of a crater on the tool rake face and consequently reduces the tool mechanical resistance and its efficiency. Diffusion phenomena were first reported by Loladze **[1962]** who showed that at conventional speed, tool wear is mainly due to abrasion and adhesion, but is dominated by diffusion process at higher speeds. Weill [1962] confirmed, by carrying out wear tests on the tungsten–molybdenum couple, that there are three wear modes depending on the cutting speed used.

A crater is usually formed at some distance from the cutting edge (Fig. 1) and it is most frequently observed when cutting steels and other high-melting-point metals at relatively high cutting speeds [Trent,1983].

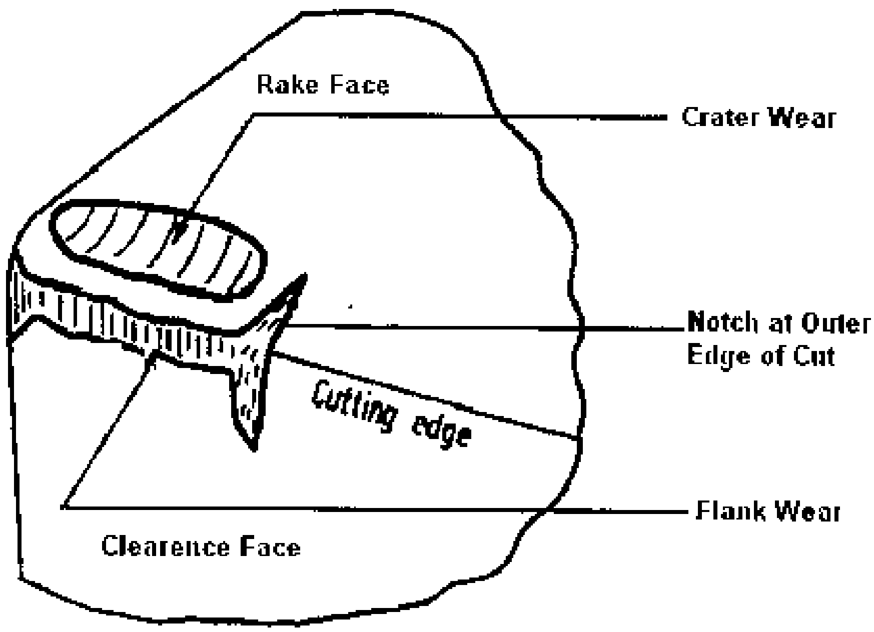


Fig. 2.1 Wear features on the cutting edge of a turning tool [Trent, 1983]

This crater gradually becomes deeper with time and may lead to the breakage of the cutting edge, rendering the tool useless.

The mechanisms produce wear scars that are referred to as flank wear, crater wear, notch wear, and edge chipping, as illustrated in Fig.2.2. Abrasive wear results from sliding of hard abrasive inclusions in the workpiece material across the face of a cutting tool. This mechanism can dominate when machining metals with carbide or oxide inclusions, metal matrix composites, carbides, and ceramics. Adhesion results from friction welding of the workpiece and tool material, which can cause portions of the cutting tool to be plucked out. Anisotropic properties of ceramics can cause cracking along grain boundaries that assists grain pluck out **[Sibold,1991]**. 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. 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. Abrasive wear results from sliding of hard abrasive inclusions in the workpiece material across the face of a cutting tool. This mechanism can dominate when machining metals with carbide or oxide inclusions, metal matrix composites, carbides, and ceramics. Adhesion results from friction welding of the workpiece and tool material, which can cause portions of the cutting tool to be plucked out.

In comparison to steel cutting tools, ceramics offer the advantages of increased resistance to abrasion due to increased hardness, improved chemical stability, better hardness retention at the elevated temperatures typical in metal cutting, and superior heat dispersal during cutting **[Adams, 1991** and **Amin ,1991]**. The biggest limitation of ceramic cutting tools is low fracture toughness. To compensate for the brittle nature of ceramic tools, strong cutting geometries are required. Large nose radii and wedge angles are used to improve the strength of cutting edges, as are honed or chamfered cutting edges . Even with strong tool geometries, 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.

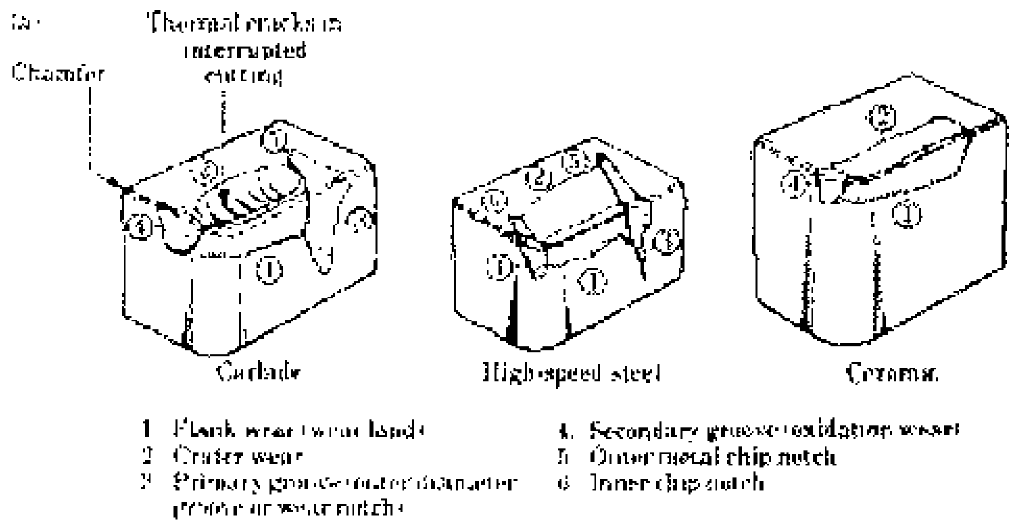


Fig.2.2 Tool wear mechanisms **[Kalpakjian 1997]**

However, 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]**. With the progress 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 aforesaid 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 workpieces machined and to vibration, which makes the cutting operation less efficient.

2.2 Cutting Fluid

Cutting fluids are used to provide lubricity in order to remove friction and control thermal-distortion by carrying away the heat, improving the machinability. At the same time they extend tool life, reduce power consumption and move metal chips. However, the use of cutting fluid generally causes economy of tools and it becomes easier to keep tight tolerances and to maintain workpiece surface properties without damages **[Sales et. al., 2001]**. These are, therefore, the key factor in machine shop productivity and production of quality machined parts **[Aronson 1994; Sluhan 1994 and Tuholski 1993]**.

Above all, during cutting fluid selection, benefits of a fluid's versatility should be weighed against its performance in each metal working application **[Aronson 1994; and State of Ohio EPA 1993]**.

Metal cutting fluids can be divided as below (Fig. 2.3):

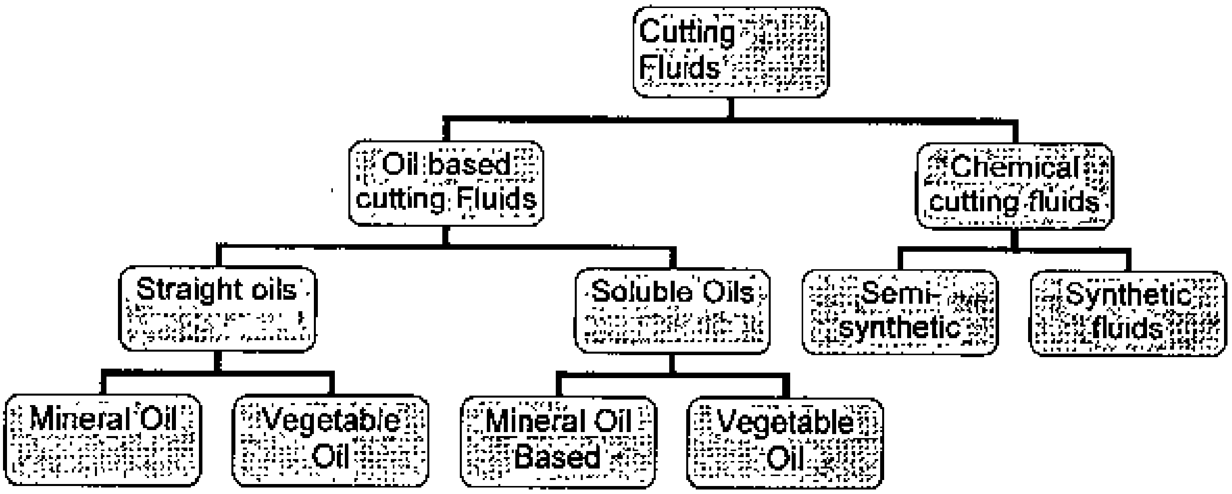


Fig.2.3 Classification of cutting fluid **[Sluhan 1994 and Bienkowski 1993]**

Straight oils cutting fluid consist of solvent-refined or hydro-treated petroleum oil or other oils of or vegetable origin. Main advantages of straight oils are that they have resistance to biological degradation and good rust protection. They also required little maintenance **[Bienkowski ,1993]**.

Soluble oils, also known water-soluble oils, are generally comprised of 60-90% mineral oil or vegetable oil, emulsifiers, and other additives **[Aronson 1994; Bienkowski 1993 and IWRC 1990]**. These offer improved cooling capabilities and good lubrication. But presence of water makes soluble oils more susceptible to rust control problems, bacterial growth and rancidity, tramp oil contamination and evaporation losses. Moreover, misting of soluble oils may produce a dirty and unsafe work environment, through slippery surfaces and inhalation hazards **[IWRC, 1996]**.

Chemical Fluids are two types Semi-synthetic fluids and Synthetic fluids. Semi-synthetic fluids contain small amount of refined based oil(5-20%) , micro-emulsifier ,water and a solution of additives. These fluids have good cooling capacity and lubricity. These fluids may cause misting, foaming and dermatitis.

Synthetic fluids contain no petroleum and mineral oil **[Sluhan ,1994 and Foltz]** and generally consist of chemical lubricants and rust inhibitors dissolved in water. These fluids are designed for high cooling capacity, lubricity, corrosion prevention and easy maintenance **[IWRC ,1996]** and make them able to handle heavy-duty grinding and cutting operations on tough, difficult-to-machine and high temperature alloys **[Sluhan ,1994]**. Despite of the benefits offered, a number of health and safety concerns, such as misting and dermatitis, remain with the use of synthetics in the shop **[Bienkowski, 1993]**. Synthetic fluids are also easily contaminated by other machine fluids such as lubricating oils and need to be monitored and maintained to be used effectively **[Aronson ,1994 and Koelsch ,1994]**.

2.3 Disadvantages of Conventional Cutting fluid

2.3.1 Biological Hazards to Human

Cutting fluids generally contain substances such as emulsifiers, stabilizers, corrosion inhibitors, biocides, fragrances and extreme pressure additives. These complex mixtures are very useful but can cause a variety of health problems such as Irritation and Rashes in skin, Dermatitis, Asthma, Hypersensitivity Pneumonitis (HP).

A long time exposure to cutting fluids can cause skin cancer **[UAW Health and Safety Department,1999]**. Cutting fluids also form a mist of small droplets that are suspended in the air and can be inhaled and ingested. When these fluids form into a mist during the machining process, they can be very irritating to the eyes, nose and throat. The larger droplets can pass into the nose and windpipe and can be swallowed. The smaller droplets can deposit in to the lungs. The inhalation of Metalworking Fluids mist, vapors and smoke over time may cause Asthma, HP and evidence has suggested that in the long term they may lead to lung cancer. "Past hazard, current danger". The repeated exposures to these insoluble fluids may also cause sensitization. The Aersolization of other contaminates that are present in the cutting fluid sumps may pose a greater threat than the mineral oil itself, the adverse health affects are not currently being researched. Cutting fluids are toxic and extremely hazardous and are exposed to an innumerable amount of people during the course of a single day.

Skin exposure is the dominant route of exposure, and it is believed that about 80 percent of all occupational diseases are caused by skin contact with fluids **[Bennett et al.,1985]**. Cutting fluids are important causes of occupational contact dermatitis, which may involve either irritant or allergic mechanisms. Water mixed fluids generally determine irritant contact dermatitis and allergic contact dermatitis when they are in touch with workers skin. Non-water-miscible fluids usually cause skin disorders such as foliculitis, oil acne, keratoses and carcinomas.

In the mid-1980s U.S. studies started to show that workers exposed to cutting fluids were developing various kinds of cancers. The international Agency for Research on Cancer has concluded that there is "sufficient evidence" that mineral oils used in the workplace are carcinogenic **[Peter et al.,1996]**. Basically, workers are exposed to cutting fluids via three routes **[Bennett et al. 1985]**; skin exposure, aerial exposure and ingestion.

U.S. studies of workers exposed to metalworking fluids have found increased numbers of asthma, bronchitis, lipid pneumonia, hypersensitivity pneumonitis (extrinsic allergic alveolitis) and fibrosis. By measuring workers' ability to breathe at the beginning of the work shift compared to the end of the work shift, researchers in the U.S. found that workers exposed to quite small amounts of metalworking fluids had a reduced ability to breathe.

2.3.2 Environmental Pollution

Manufacturing by machining constitutes major industrial activities in global perspective. Like other manufacturing activities, machining also leads to environmental pollution **[Ding, 1998 and Hong et al. 1999]** mainly because of use of cutting fluids. Environmental is polluted due to breakdown of the cutting fluids into harmful gases at high cutting temperature These fluids often contain sulfur (S), phosphorus (P), chlorine (Cl) or other extreme-pressure additives to improve the lubricating performance. Disposal of this type spent cutting fluids offer high risk of water pollution and soil contamination.

2.3.3 Technological Limitation

The application of cutting fluid may not always reduce the cutting tool wear as is commonly believed. Rather some conditions like machining steels by carbide tools, the use of coolant may increase tool wear.

It has been experienced **[Shaw et al. 1951]** that there was more tool wear when cutting with flood cooling than cutting dry in case of machining AISI 1020 and AISI 4340 steels by M-2 high speed steel tool cutting.

Seah et al. **[1995]** also reported that at the first stage of machining (first 40 seconds or so), tool wear was faster in wet cutting than in dry cutting. Later on, the wear rate stabilized and was somewhat the same for both dry and wet cutting.

Another experimental investigation was conducted **[Cozzens et al., 1995]** on single point boring. This was aimed to study the role of cutting fluid, tool and workpiece material, tool geometry and cutting conditions on machinability. The results indicated that the cutting fluid conditions had no significant effect on surface texture, forces and built-up edge. Since boring is a high-speed operation and lubrication is ineffective, no effect was seen on the forces. However, the cutting fluid was found to have a significant effect on surface integrity.

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.

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]**.

2.3.4 Economical Aspects

Traditionally, the manufacture of a product had been attempted to be done as quickly and inexpensively as possible. Now that more environmental regulations are being put in place, 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. So where an extra cost is needed. Cutting fluid system requires of additional systems for pumping, local storage, filtration, temporary recycling, and cooling and large space requirement which are quiet costly. Thus cutting fluids affects the whole economy of a manufacturing system.

The machining costs (labour and overhead) in the US alone are estimated to be $300 billion/year **[Komanduri and Desai ,1983]**. The costs associated with the use of cutting fluids is estimated to be about 16% of the manufacturing costs **[Byrne and Scholta 1993]** which is many more times than the labour and overhead figures quoted above. A recent study in Germany found that 16% of machining cost in the high volume manufacturing industries is associated with the use of cutting fluids (procurement, maintenance and disposal) while only 4% of the cost was associated with cutting tools **[Aronson,1995]**. The use of cutting fluids also requires additional equipment for plant housekeeping.

2.4 Minimum Quantity of Lubrication

Extensive researches have been done try to minimize, or even completely avoid, the use of cutting fluid in machining processes. The reason for this is the high percentage of fluid costs in the overall manufacturing costs (reaching 17% in some cases), ecological and legal demands and human health among others **[Heisel et.al, 1998 and Kalho¨fer,1997]**. Cutting fluids, most of the times, are difficult and expensive to recycle, can cause skin and lung diseases to the machine operator and air pollution. In 1992 in German industries, the volume of discarded cutting fluid used in machining processes reached 60% of the total amount of lubricant oils. All costs involved with cutting fluids (purchasing, recycling, chip drying, etc.) represent 7.5–17% of the manufacturing costs of a part, which in many cases is even higher than tool costs **[Kalho¨fer,1997 and Derflinger, 1999]**. On the other hand, many times, the use of cutting fluid is important in a machining process to cool and lubricate tool and workpiece, making tool life longer and guaranteeing the workpiece quality. Besides that, in some operations such as drilling, for example, cutting fluid is important to remove the chips from inside the holes, thus preventing drill breakage **[Heisel et.al, 1998]** Therefore, it is important to find a way to accomplish machining processes without or with little cutting fluid and, at the same time, promoting long tool life and good workpiece quality. 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]**

Minimum Quantity Lubrication (MQL) by agents like soluble and vegetable oils appears to be a promising technique for effective cooling without the problems associated with conventional cutting fluid applications. But it is also essential to be assured that productivity and overall economy are not affected while deriving the environmental benefits of Minimum Quantity Lubrication (MQL).

2.5 Vegetable Oil as a Cutting Fluid for MQL Machining

For a typical machining operation, the fluid's lubrication and heat transfer performance properties are crucial to achieving a successful result. To contain the heat generated during machining, it is important to provide the means of controlling its development and minimizing its detrimental effects on the cutting process.

Machining temperature also impacts machine cycle times and production rates. By reducing friction and heat generation, effective lubrication reduces overall machining temperatures, which improves workpiece quality and overall process productivity.

Mineral oil-based coolants tend to be more lubricious than synthetic products. Most of them also cost less, which accounts for their being employed in the majority of applications. Their composition and raw material base consist primarily of naphthenic oils, with the addition of specific lubricity ingredients and extreme pressure agents and other additives[**Ulrich, 1979**].

As a proven and tested technology, vegetable oils have been recognized as having superior lubricating properties since the 1960s. Their constituents have been cultivated and refined for specific performance properties and technical requirements. The lubricating film layer provided by vegetable oils is intrinsically strong and lubricious. As a result, these coolants have lubricity that is significantly higher than that of mineral oil. In addition, vegetable provides durable lubrication. Even for heavy-duty machining of demanding material, vegetable-oil cutting fluids can be utilized without requiring extreme pressure additives.

Coolants utilizing the vegetable oil technology tend to be costlier than alternative products. Expensive ingredients are required to enhance their biological stability. The additional cost, however, is offset by the gains in productivity, as well as the many opportunities for cost reduction when compared with alternative coolants.

The highly lubricating properties of vegetable oil are made possible by the fundamental composition of the vegetable oil molecules, as well as the chemical structure of the oil itself. For cutting fluid based on vegetable oils, lubricity arises from the intrinsic "oiliness" of its vegetable oil constituents; and its properties are the direct result of the vegetable oil's "smart molecules." These molecules are long, heavy, and dipolar in nature; that is, the ends of the molecules have opposing electrical charges.

The "polar heads" of the molecules have a great chemical affinity for metal surfaces and attach themselves to the metal like little magnets. The result is a dense, homogeneous alignment of vegetable oil molecules, perpendicular along the metal surface that creates a thick, strong, and durable film layer of lubricant. This strong lubricating film gives the vegetable oil a greater capacity to absorb pressure.

In contrast, mineral oil molecules are non-polar in nature. They form a random alignment along a metal surface, which yields an inherently weaker layer of lubrication. Augmenting the mineral oil with polar additives cannot overcome this natural difference in film strength between vegetable and mineral oils.

Viscosity is another vegetable oil property that has an important effect on machining productivity. If the lubricating oil is too thick or too thin, cutting tool wear is increased. The higher viscosity index of vegetable oil ensures that vegetable oils will provide more stable lubricity across the operating temperature range. When the machining temperature increases, the viscosity of vegetable oil drops more slowly than that of mineral oil. Conversely, as the temperature falls, vegetable oil remains more fluid than mineral oil, facilitating drain-off from chips and workpieces. And a higher flash point yields opportunities for increased rates of metal removal as a result of reduced smoke formation and fire hazard. [**Ulrich ,1979].**

While vegetable oil molecules are quite homogeneous in size, mineral oil molecules vary in size over a significantly wider spectrum. As a result, the physical properties of mineral oil such as its viscosity at vaporizing and boiling temperatures, for example are more susceptible to variation. The higher boiling point of vegetable oil and greater molecular weight result in considerably less loss from vaporization and misting. And, due to the higher molecular weight, the fallout becomes confined to a smaller area. The result is a healthier and cleaner work environment, with less mist in the air. Also, vegetable oils are nontoxic to the environment. For the present work, olive oil has been used as a cutting fluid.

2.6 Selection of Cutting Tool

All cutting operations require tool materials that can withstand the difficult conditions produced during machining. There are primarily three problems all cutting tools face:

- wear at the cutting edge,
- heat generated during the cutting process, and
- thermo-mechanical shock.

As cutting tool has to withstand large cutting forces, speed, feed etc. , the tool materials should have good wear resistance, hardness, toughness, , and chemical stability. In general, increased hardness improves wear resistance but is associated with decreased toughness. Basically, cutting tool material properties depend on machining conditions and workpiece properties,

According to the tools material most common cutting tools used in turning operation are:

- High-speed steels (HSS) tool
- Carbon tool steel tool

- Polycrystalline cubic boron nitride (PCBN)
- Diamond tool
- Carbides tool

High-speed steels (HSS) are widely used in cutting tool of different types of machining operation especially in turning, drilling and milling. High-speed steels have the lowest hardness and highest fracture toughness of general use tools. The primary reason high-speed steel tools are not used more extensively is that they soften significantly at temperatures above 500°C. This softening behaviour 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.

Aluminum oxide (Al_2O_3) tools make up one of the most important classes of ceramic cutting materials. They have very high hardness and wear resistance, while also providing better chemical stability than carbides **[Kalpakjian ,1997]**. Al_2O_3 based tools can be divided into two groups: white ceramics that consist of pure alumina mixed with 2% to 5% zirconia (ZrO_2), and black ceramics that add 30% to 40% TiC or TiN to alumina **[Edwards ,1993]**. The zirconia in white ceramics is added to improve fracture toughness compared to pure alumina, without significantly compromising hardness and wear resistance. The TiC or TiN additions in black ceramics improve hot hardness of these tools compared to white ceramics, but at the expense of decreased fracture toughness. Thus, white ceramics can be used for more aggressive cutting conditions where impact loading or thermal shock may occur, while black ceramics are reserved for finishing conditions on hard work pieces where consistent mechanical and thermal loads are experienced.

Sialons are materials based on silicon nitride (Si3N4), and are formed by sintering a mixture of SiO_2, Al_2O_3, Si_3N_4, Y_2O_3, and MgO powders. Sintering causes the SiO_2 to react with Al_2O_3 and Y_2O_3 to form a liquid that reacts with the Si_3N_4 to form silicon aluminum oxy-nitride. Due to chemical affinity, sialons diffuse rapidly into steels and are not suitable for cutting these alloys. However, they maintain hardness at very high temperatures, which makes them ideal for machining heat-resisting super alloys at high cutting speeds. They are capable of material removal rates 4 times higher than ceramic-coated carbide tools when used to machine super alloys **[Mehrotra, 1998]**.

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 grey cast iron and some nickel-based alloys **[Jack ,1986]**.

It has been possible to synthetically produce diamonds since 1958. Diamond particles are produced by heating carbon to approximately 1500^{0}C and applying pressures of 6 GPa, much like the process to convert boron nitride from hexagonal to cubic form **[Edwards ,1993]**. To form a cutting tool, 1-30 µm diamond particles are sintered at high temperature and pressure onto a cemented carbide base **[DeGarmo**

et al. ,1988]. The carbide base provides a ductile support for the hard and brittle diamond layer. This technique is also used often in the production of PCBN cutting tools. However, diamond tools exhibit excellent wear resistance in applications like machining high silicon content aluminum, but their performance on steel is poor. This is because the carbon that comprises diamond tools is a major alloy element in steels, so at the high interface temperatures that occur during machining, the very expensive diamond tools diffuse rapidly into the work piece.

Polycrystalline cubic boron nitride cutting tools used to machine hard materials. Traditionally, machining of hardened steel components has been the domain of grinding. Recently, CBN (cubic boron nitride) tooling has proven to be a viable alternative, providing both environmental and cost benefits. The main advantages of CBN tools are that they maintain hardness even at very high temperatures **[Tabuchi et al. ,1978]**, have low solubility in iron, and good fracture toughness for a ceramic **[Bossom,1990]**. That's why, 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]**.It offers the possibility of greater process flexibility, reduced machining time, lower energy consumption, swarf recycling possibilities, and the optional use of a coolant. Despite these evident advantages, industrial realization of hard machining has not risen in comparison with the potential spectrum of applications. The clearly unsatisfactory industrial acceptance of hard machining technology can be attributed partly to insufficient knowledge of the component behavior of hard machined technical surfaces and partly to the uncertainty about the attainable accuracies-to-size.

Moreover, CBN tools are very expensive and justified for very special work materials and requirements where other tools are not effective.

Carbide tools were, therefore, developed in the 1930's to allow machining at higher cutting speeds (and increased production rates), **[Kalpakjian, 1997]**. These tools now consume an estimated 70% of the machining market. Because the tools are typically pressed and sintered from ceramic powders (often with a cobalt binder material), they are sometimes called sintered carbides or cemented carbides. There are two basic subsets of carbide tools: tungsten carbide (WC) and titanium carbide (TiC), WC tools being the most prevalent.

Pure WC is very hard, but also brittle. To improve toughness, WC powder is mixed with 5-15% cobalt (weight percentage). 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]**. However, An optimal grain size and cobalt percentage must be determined to allow the hardness and toughness required for a particular cutting operation.

Chapter-3

Objective of the Present Work

The main objective of the present work is to make a thorough and systematic experimental investigation on the roles of minimum quantity lubrication (MQL) by vegetable oil-based cutting fluid (olive oil) on the major machinability characteristics of different types of steel in respect of:

i. tool wear and tool life

ii. surface roughness

in turning commercial steel namely alloy steels (AISI 9310 steel& AISI 1040) by the industrially used uncoated carbide tool (SNMG20408 TTS) at different speeds, feeds and depth of cut combinations. The results are being expected to enable optimisation of the MQL process and machining conditions.

The scopes of the present work are :

(a) Design and fabrication of a

i. MQL machining set up

ii. suitable nozzle for MQL jet

(b) Analysis of data by

i. measuring tool wear (flank wear) under microscope

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

iii. measuring surface roughness

Chapter-4

Design and Fabrication of MQL Applicator

It has already been observed through previous research that proper application of MQL may play vital role in providing not only environment friendliness but also some techno-economical benefits.

For achieving substantial technological and economical benefits in addition to environment friendliness, the MQL system needs to be properly designed. MQL system should be designed such a way that MQL jet reach as close to the actual hot zones as possible which is very important for effective cooling. MQL system should also ensure minimum consumption of cutting fluid by pin-pointed impingement and only during chip formation

4.1 Design and Fabrication of the MQL System

Minimum quantity lubrication (MQL) means a flow rate of cutting fluids 50 to 500 ml/hour. It is about three to four orders of magnitude lower than the amount commonly used in flood cooling condition, where, for example, up to 10 liters of fluid can be dispensed per minute.

The MQL applicator was designed to supply MQL at 8 bar which is high enough pressure to impinge at high speed through the nozzle at the cutting zone. The photographic view of the MQL applicator is shown in Fig 4.1.

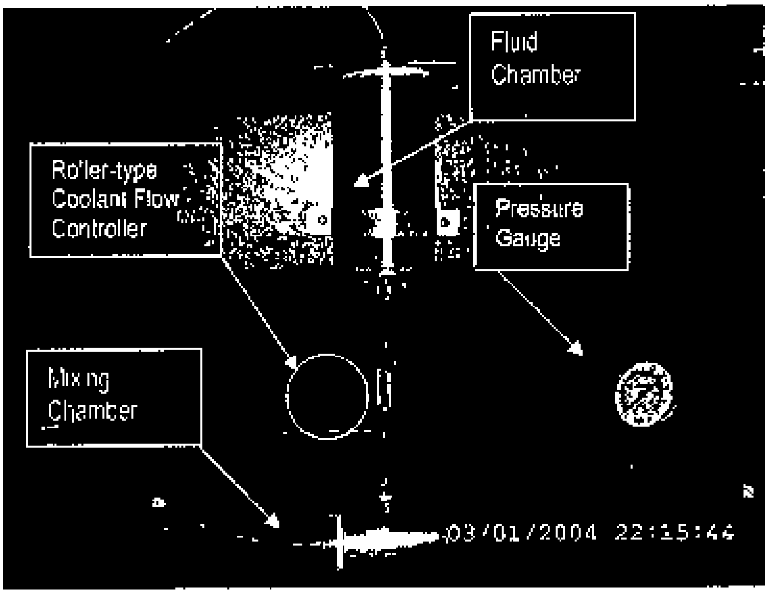


Fig 4.1 Photographic view of the MQL Applicator

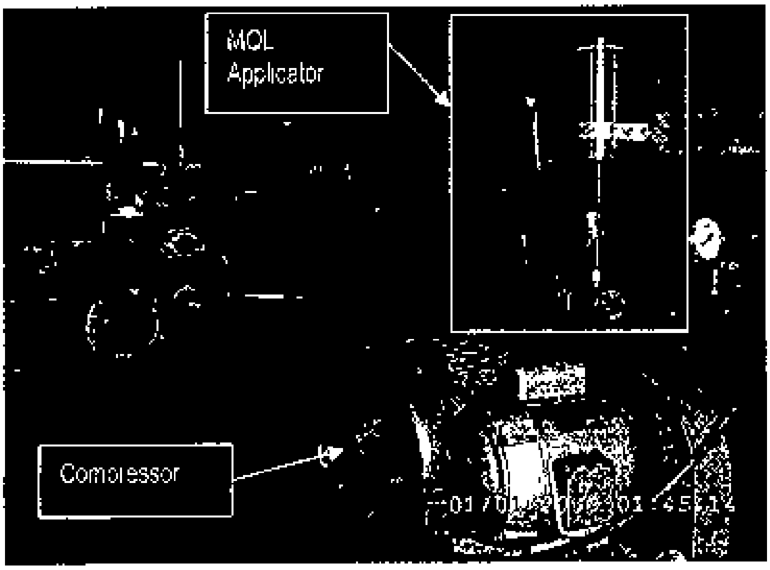


Fig 4.2 Photographic view of the experimental set-up

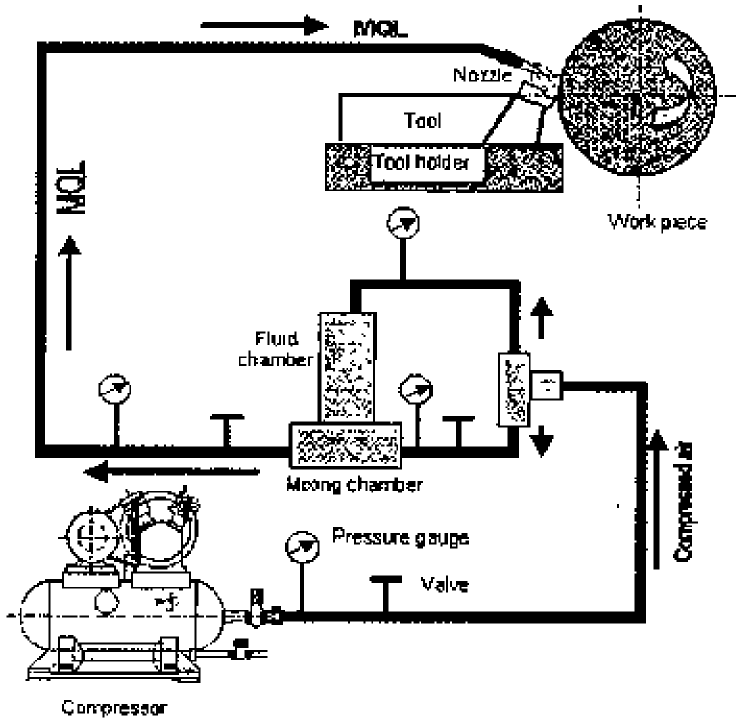


Fig 4.3 Schematic views of the Experimental Set-up

In this system, a compressor is used to supply air at a high-pressure of 6 bars. This high-pressure air from the compressor enters into two chambers. One is fluid chamber and another is mixing chamber. The fluid chamber is connected at the bottom with the mixing chamber by very 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. The compressed air through the upper inlet port creates pressure to cause the fluid to go continuously to the mixing chamber through controller at a constant rate. The air and the vegetable oil are mixed in the mixing chamber so that the mixture of vegetable oil and air is impinged at a high speed through the nozzle at the chip-tool interface. The photographic and schematic views of the experimental set-up are shown in Fig 4.2 and Fig 4.3 respectively. During experimentation the thin but high velocity stream of MQL was projected 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.

4.2 Design and Fabrication of the Nozzle

The nozzle has been designed so that the nozzle spray pattern, covering area and MQL rate can be controlled. The nozzle developed and used and its setting along auxiliary cutting edge of the tool are shown in Fig.4.5 and Fig.4.4 respectably.

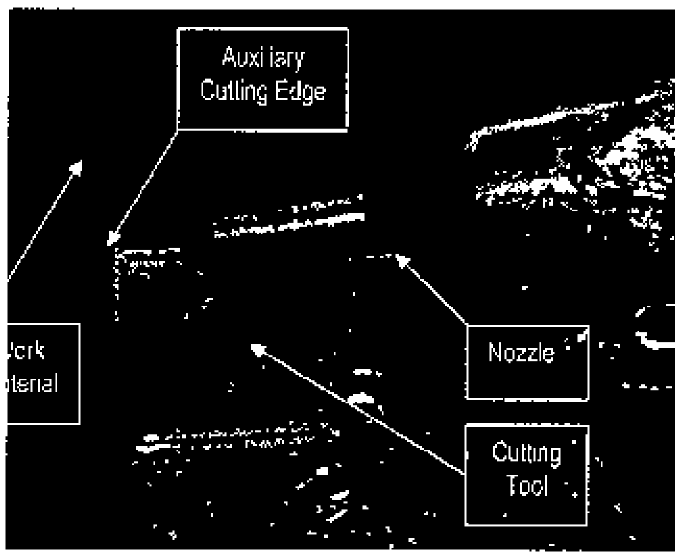


Fig. 4.4 Photographic view of the nozzle used for MQL delivery at the cutting zone

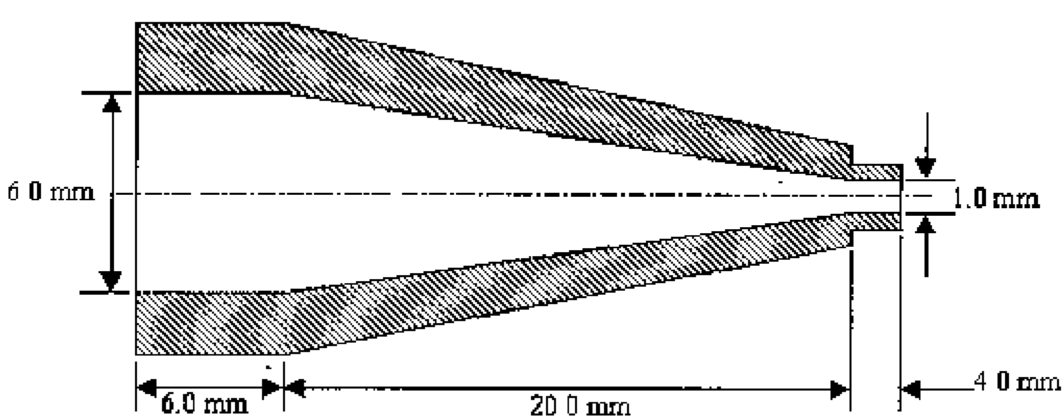


Fig.4.5 Schematic view of the nozzle used for MQL delivery

The nozzle having bore diameter reduction ratio, i.e. inlet diameter to outlet diameter, 6:1 is attached to the tool post with a magnetic stand and is connected with flexible pipe to supply MQL in the form of jets 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:

i. less interference with the flowing chips
ii. high speed MQL jet reaching quite close to the chip-tool contact zone
iii. simple and low cost.

Chapter-5

Experimental Investigations

5.1 Experimental Procedure and Conditions

The turning operations were performed using a powerful lathe (15 hp/11kW: Lehman Machine Company, USA). Workpiece materials were AISI-9310 steel and AISI-1040 steel. Machining was carried out with uncoated carbide inserts at a constant cutting velocities (V_c) and feeds (S_o) under dry and MQL conditions.

The compositions, strength, hardness and industrial use of this steel are given in Table 5.1

Table 5.1 Properties of the used steels.

Work material	BHN	Chemical composition (wt %)	Applications
AISI 1040 steel	180	C -0.410, Mn -0.700, P -0.040, S -0.050	• Automobile axles • Spindles • Lightly stressed gears
AISI 9310 steel	257	C-0.12, Mn-0.55, P-0.025, S-0.025, Si-0.25, Cr-1.3, Ni-3.4, Mo-0.14	• Shafts & crank shafts • Automobile axles • High strength studs and bolts

Machining industries generally use sintered carbide tools, both uncoated and coated for machining steels. High performance tools like ceramics toughened and strengthened by stabilized zirconia [**Mondal et al. 1992**] metals [**Tuan** and **Brook 1990** and **Wang et al.1993**] and SiC whiskers [**Li and Low 1994**] and CBN [**Narutaki** and **Yamane 1979**] are also used now-a-days by the modern industries. But such tools are not only expensive but also require very rugged and powerful machine tools, which common industries cannot always afford. Diamond tools [**Hinterman** and **Chattopadhyay 1993**] are excellent performing for exotic materials excepting ferrous metals which graphitise diamond.

Considering common interest and time constraint only uncoated carbide inserts of grade P30 have been used for the present work. Effectiveness of cooling and the related benefits depend on how closely the MQL jet can reach the chip-tool and the work-tool interfaces where, apart from the primary shear zone, heat is generated.

The tool geometry is reasonably expected to play significant role on such cooling effectiveness. Keeping this view a standard tool configuration namely SNMG (Sandvick) has been undertaken for the present investigation. The inserts were clamped in a PSBNR 2525 M12 (WIDIA) type tool holder.

The positioning of the nozzle tip with respect to the cutting insert has been settled after a number of trials. The final arrangement made and used has been shown in Fig.4.4. During experimentation, the thin but high velocity stream of MQL was directed 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 aforementioned interfaces and the auxiliary flank effectively as well. The photographic view of the experimental set-up is shown in Fig.4.2.

The machining responses that have been studied and evaluated for assessing the effect on tool wear and surface finish of the steel specimens under both dry and minimum quantity lubrication (MQL by vegetable oil) conditions are indicated in Table 5.2. It has already been reported [**Dhar et al 2004; Paul et al. 2000** and **Seah et al. 1995**] that use of conventional cutting fluids (wet machining) does not serve the desired purpose in machining steels by carbides, rather reduces tool life and often may cause premature failure of the insert by brittle fracture.

The experimental conditions are given in Table 5.2.

Table 5.2 Experimental conditions

Machine tool	Lathe Machine (USA), 15 hp	
Work material	AISI-9310 steel (φ125 X 540 mm) AISI-1040 steel(φ*105* X540 mm)	
Cutting tool (insert)		
Cutting insert	Uncoated Carbide, SNMG 120408 TTS, (Sandvick)	
Tool holder	PSBNR 2525M12(ISO specification), Widia	
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	194 m/min and 330m/min	
Feed rate, S_o	0.18 mm/rev	
Depth of cut, t	1 mm	
MQL supply	Air: 6 bar, Lubricant: olive oil, 200ml/h (through external nozzle).	
Environment	Dry and Minimum Quantity Lubrication (MQL) by Vegetable Oil	

Almost at a constant velocity with same feed, machining of the steel bars was taken in both DRY and MQL conditions.

Keeping in view less significant role of depth of cut (t) on cutting temperature, saving of work material and avoidance of dominating effect of nose radius on cutting temperature, the depth of cut was kept fixed to only 1 mm, which would adequately serve the present purpose. The machining responses have been monitored and studied using sophisticated and reliable equipments and techniques as far as possible.

5.1.1 Calibration of the MQL Set up.

Calibration of flow rate of the MQL set up was investigated before experimental tests.

5.1.2 Assessment of Tool Wears

The life of the tools is a function of tool wear. Cutting tool which ultimately fail by systematic gradual wear, is generally assessed at least for R&D work, by the average value of the principal flank wear (V_B), which aggravates cutting forces and temperature and may induce vibration with progress of machining. The pattern and extent of wear (V_S) of the auxiliary flank affects surface finish and dimensional accuracy of the machined parts. Growth of tool wear is sizeably influenced by the temperature and nature of interactions of the tool-work interfaces, which again depend upon the machining conditions for given tool-work pairs.

During machining under each condition, the cutting insert was withdrawn at regular intervals and then the salient features like, V_B, V_S etc. were measured under metallurgical microscope (Carl Zesis, 351396, Germany) fitted with micrometer of least count 1μm. At the end of machining and attaining 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.

5.1.3 Measurement of Surface Roughness

Surface finish was measured by a Talysurf (Surtronic 3+ Roughness Checker, Taylor Hobson, UK) using a sampling length of 0.8 mm. The photographic view of the surface roughness technique for measuring surface roughness is shown in Fig.5.1

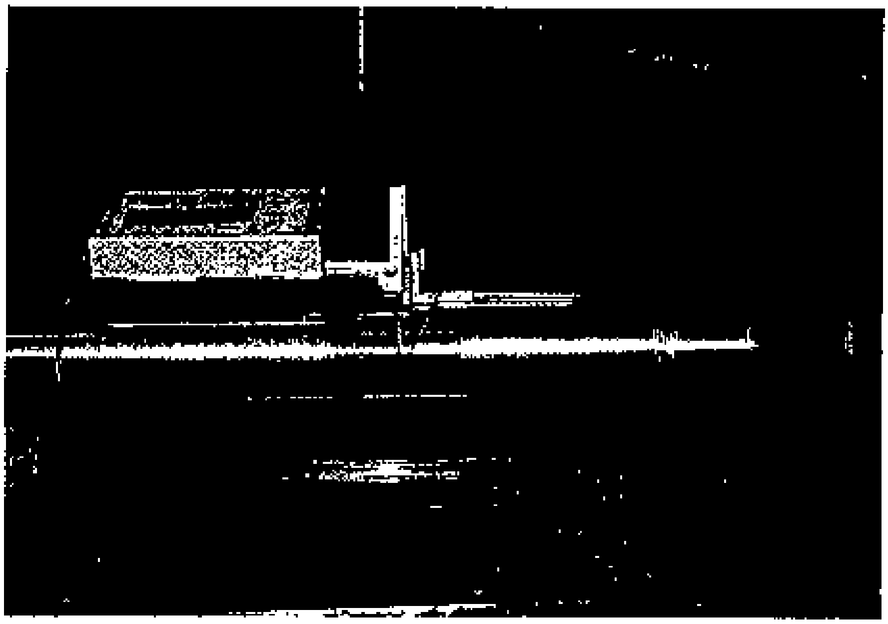


Fig. 5.1 Photographic view of the surface roughness measuring technique

5.2 Experimental Results

5.2.1 Cutting tool wear

Tool wear in machining is defined as the amount of volume loss of tool material on the contact surface due to the interactions between the tool and workpiece. Like most wear applications, tool wear has proved difficult to understand and predict

Cutting tools may fail by brittle fracture, plastic deformation or gradual wear. Turning carbide inserts having enough strength, toughness and hot hardness generally fail by gradual wears. With the progress of machining the tools attain crater wear at the rake surface and flank wear at the clearance surfaces, as schematically shown in Fig.5.2 due to continuous interaction and rubbing with the chips and the work surfaces respectively. Among the aforesaid wears, the principal flank wear is the most important because it raises the cutting forces and the related problems.

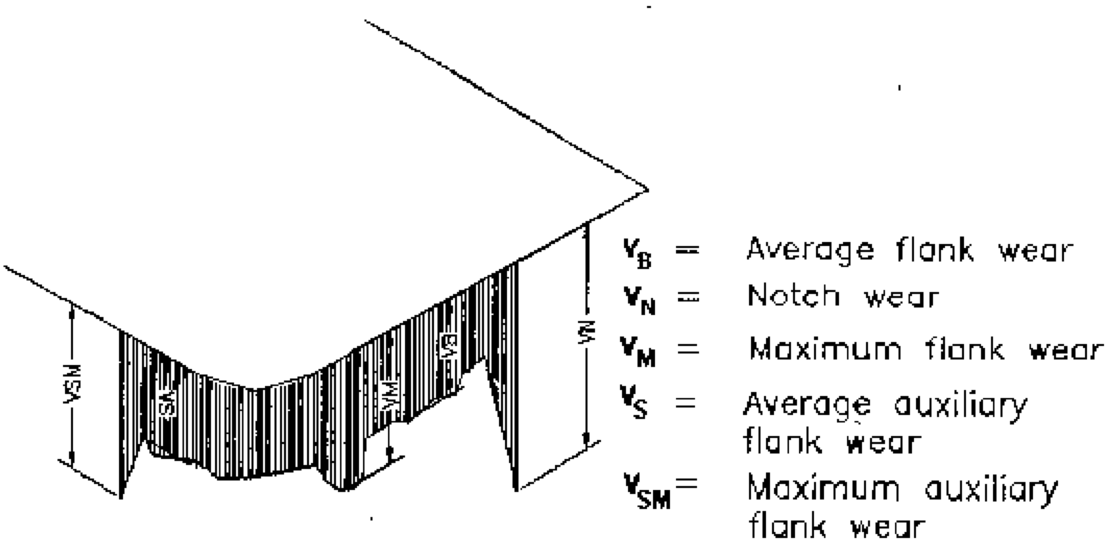


Fig.5.2 Geometry of wear of turning tool | **Trent 1979**]

The life of carbide tools, which mostly fail by wearing, is assessed by the actual machining time after which the average value (V_B) of its principal flank wear reaches a limiting value of 0.3 mm **[Ezugwu et al. 2005]**. Therefore, attempts should be made to reduce the rate of growth of flank wear (V_B) in all possible ways without much sacrifice in MRR.

Fig.5.3 & Fig.5.4 clearly shows that average principle flank wear, V_B decreased substantially by MQL by vegetable oil.

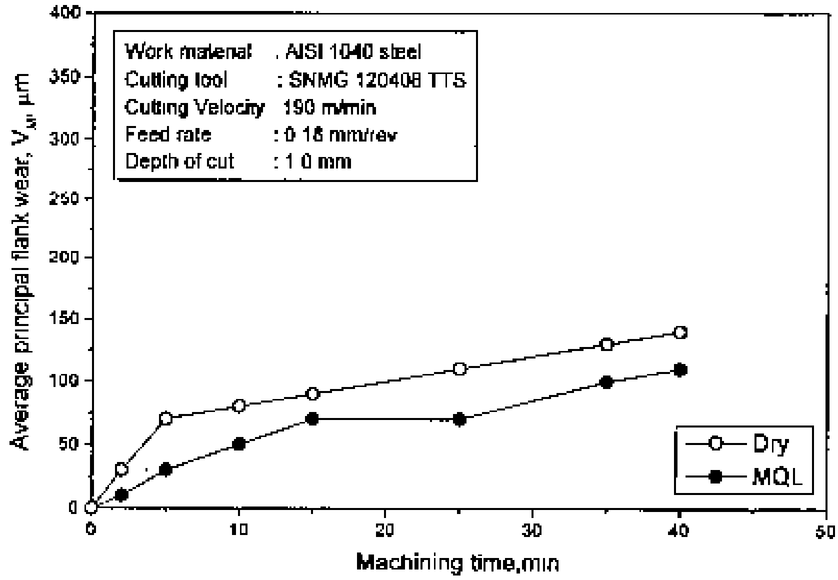


Fig.5.3 Growth of average flank wear with time under dry and MQL **by vegetable oil** conditions in turning AISI 1040 steel

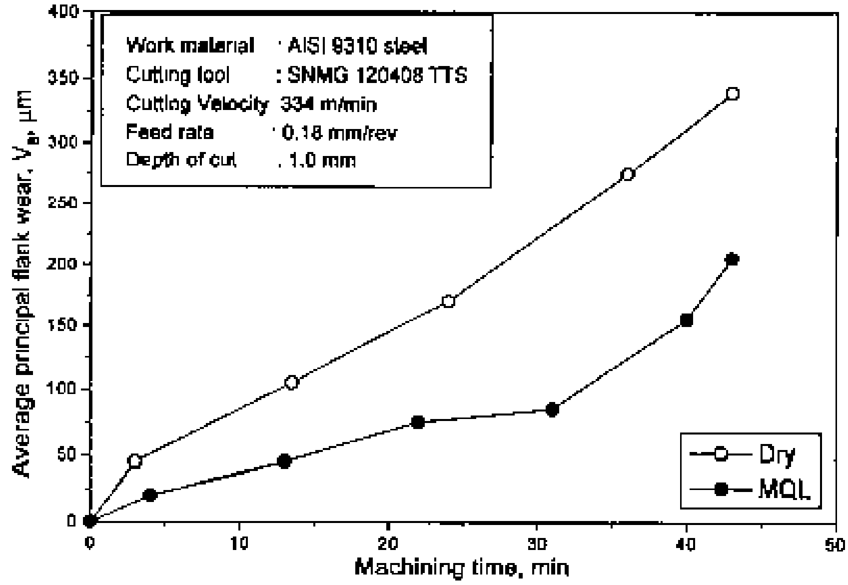


Fig.5.4 Growth of average flank wear with time under **dry** and **MQL by vegetable oil** conditions in turning AISI 9310 steel

The cause behind reduction in V_B observed may reasonably be attributed to substantial reduction in the cutting temperature by MQL by Olive

Fig.5.5&Fig5.6 shows that maximum flank wear (V_M) has also decreased sizeably due to proper temperature control under MQL by vegetable oil in turning both type of steels.

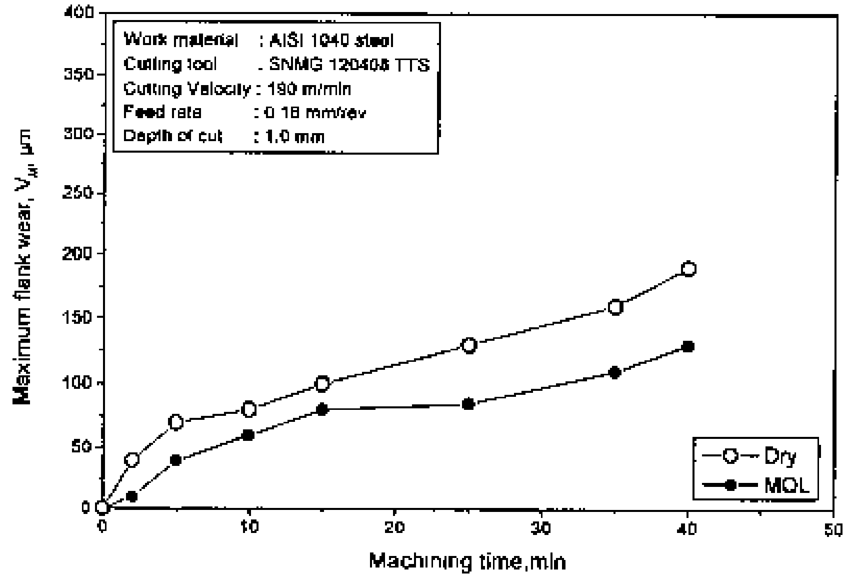


Fig.5.5 Growth of maximum flank wear, V_M with time under **dry** and **MQL by vegetable oil** conditions in turning AISI 1040 steel.

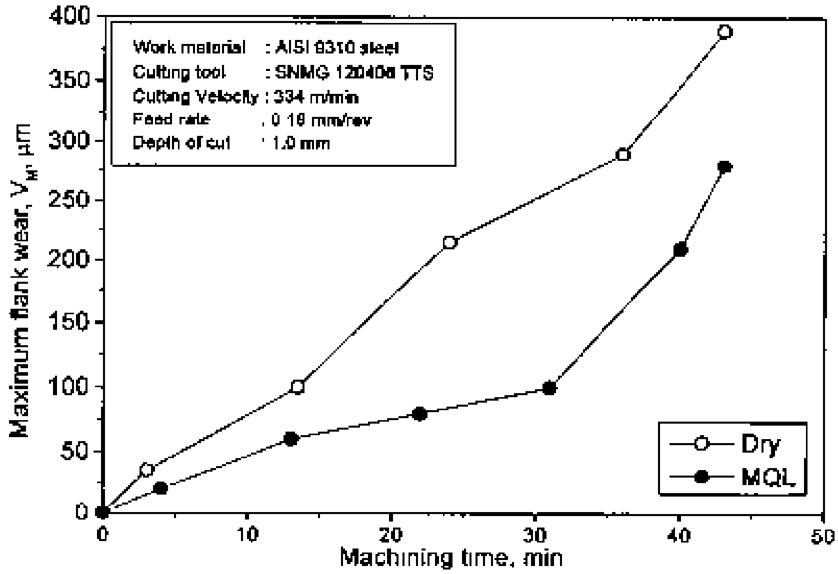


Fig.5.6 Growth of maximum flank wear, V_M with time under **dry and MQL by vegetable oil** conditions in turning AISI 9310

Oil particularly 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 sensitive to temperature. Because of such reduction in rate of growth of flank wear the tool life would be much higher if MQL by olive oil is properly applied. Auxiliary flank wear (V_S), though occurs less intensively, also plays significant role in machining by aggravating dimensional inaccuracy and roughness of the finished surface.

It appears from Fig.5.7&Fig5.8 that auxiliary flank wear (V_S) has also decreased sizeably due to proper temperature control under MQL by vegetable oil.

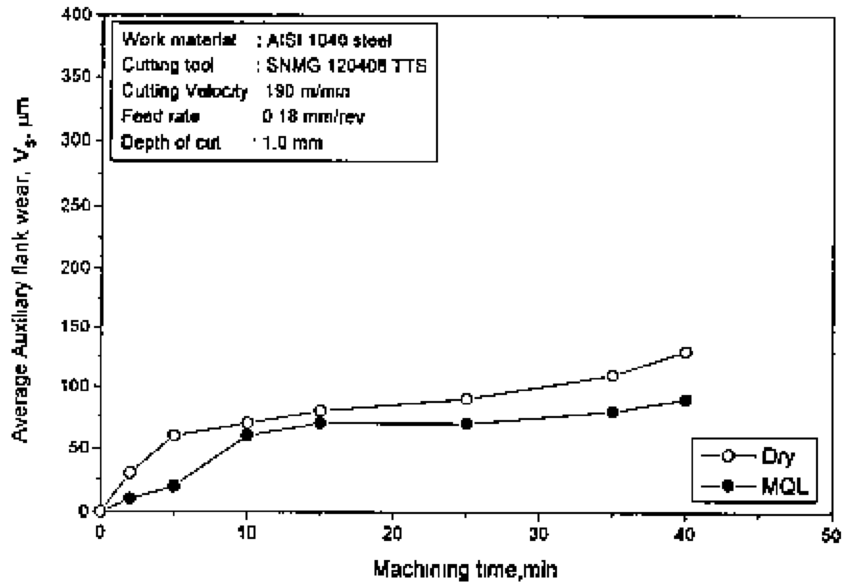


Fig.5.7 Growth of auxiliary flank wear with time under **dry** and **MQL by vegetable oil** conditions in turning AISI 1040 steel.

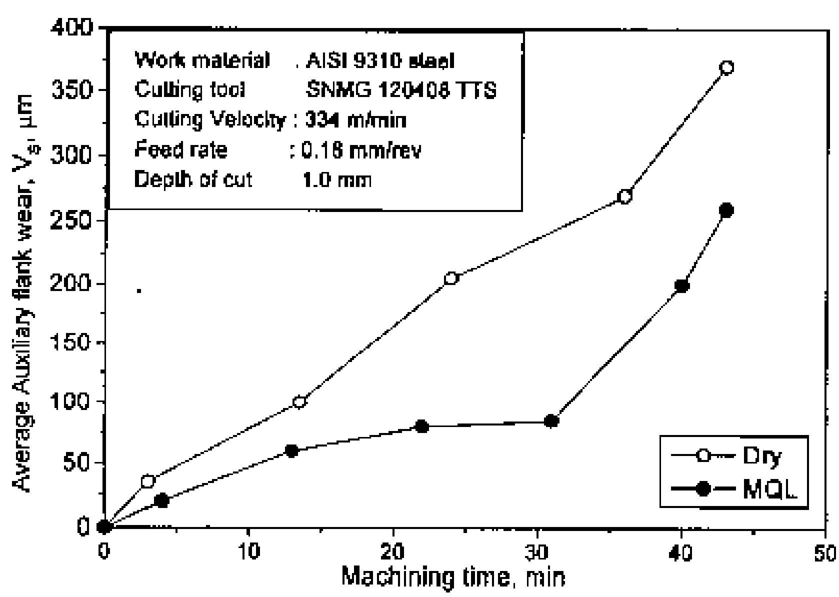
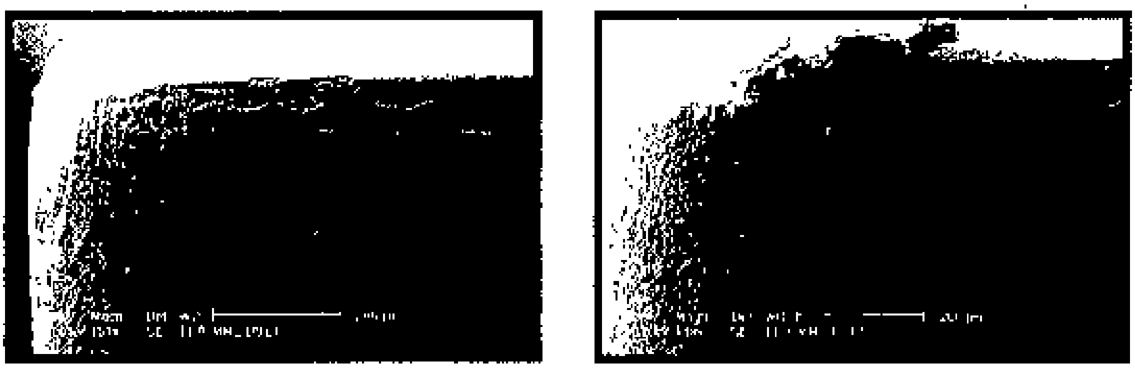


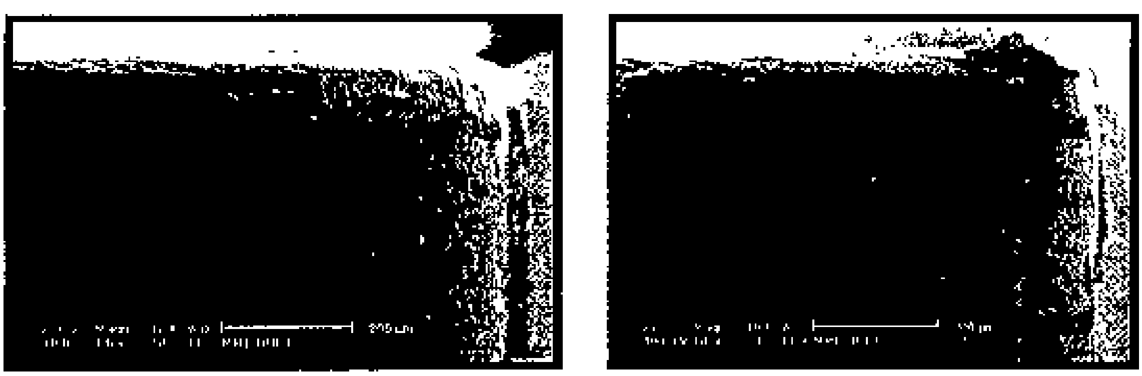
Fig.5.8 Growth of auxiliary flank wear with time under **dry** and **MQL by vegetable oil** conditions in turning AISI 9310 steel.

The pattern and extent of wear that developed at the different surfaces of the tool tips after being used for machining the AISI 1040 steel and AISI 9310 steel ,over reasonably long period have been observed under SEM to see the actual effects of different environments on wear of the carbide insert of present configuration. The SEM views of principal and auxiliary flank wear of the worn out insert of AISI 1040 steel and AISI 9310 steel after about 40 and 45 minutes of machining of the steel under dry and MQL conditions have been shown in Fig.5.9 & Fig.5.10 and Fig.5.11 &Fig.5.12 respectively.



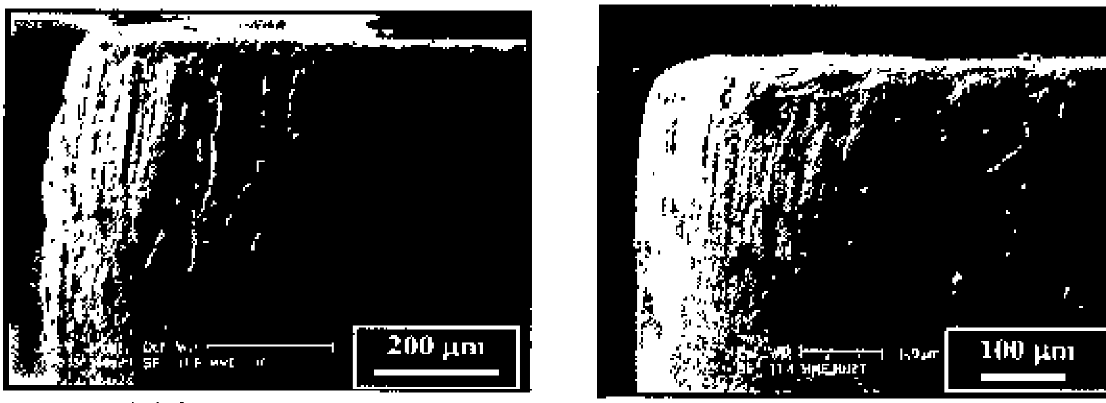
(a) Dry machining **(b) MQL machining**

Fig.5.9 SEM views of principal flank wear of the worn out insert after turning AISI 1040 steel for 40 minutes under (a) dry, (b) MQL conditions



(a) Dry machining **(b) MQL machining**

Fig.5.10 SEM views of auxiliary flank wear of the worn out insert after turning AISI 1040 steel for 40 minutes under (a) dry, (b) MQL conditions



(a) Dry machining (b) MQL machining

Fig.5.11 SEM views of principal flank wear of the worn out insert after turning AISI 9310 steel for 45 minutes under dry and MQL conditions.

(a) Dry machining (b) MQL machining

Fig. 5.12 SEM views of auxiliary flank wear of the worn out insert after turning AISI 9310 steel for 45 minutes under dry and MQL conditions.

5.2.2 Surface Roughness

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

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. Surface roughness has been measured every time when the tool wear was measured . The photographic view of the surface roughness technique for measuring surface roughness is shown in Fig.4.10.

The surface roughness attained while machining of AISI 1040 and AISI 9310 steels by the sharp carbide insert (SNMG 120408-PM) under dry and MQL conditions are shown in Fig.5.13 and 5.14 respectively.

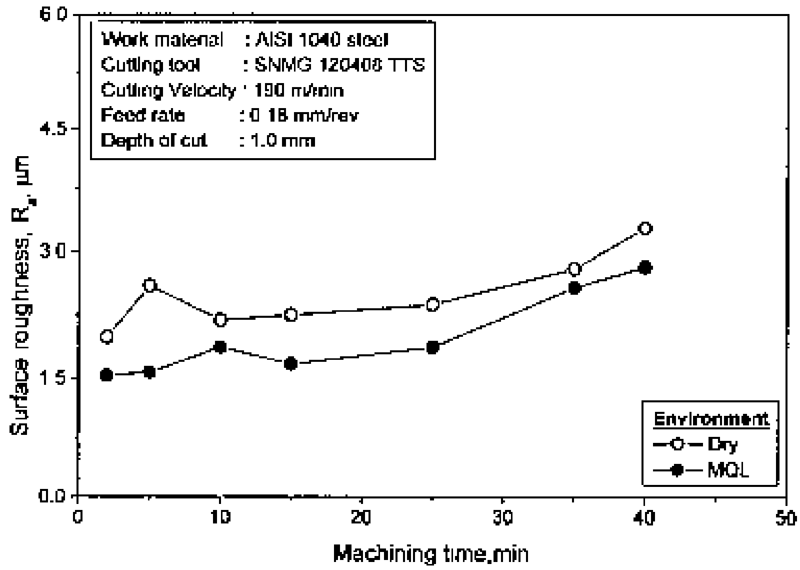


Fig.5.13 Variation in surface roughness with progress of turning steel by **SNMG** insert under **dry** and **MQL by vegetable oil** conditions in turning AISI 1040 steel.

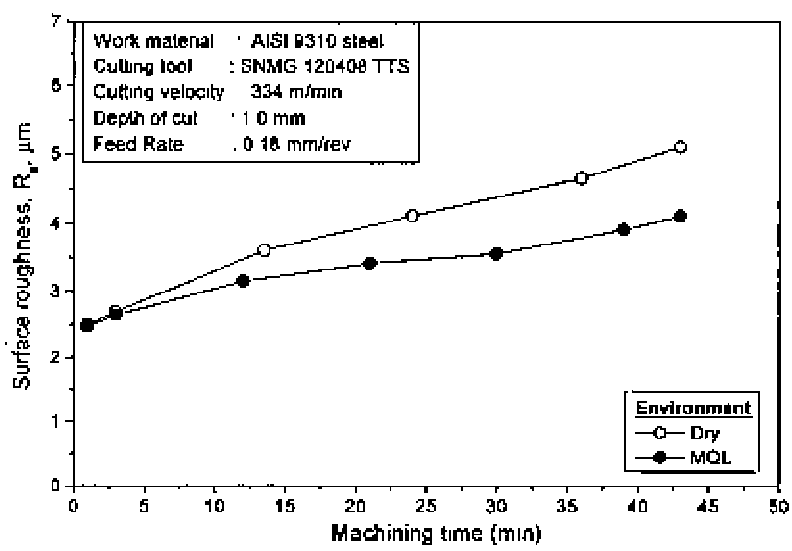


Fig.5.14 Variation in surface roughness with progress of turning steel by **SNMG** insert under **dry** and **MQL by vegetable oil** conditions in turning AISI 9310 steel.

Chapter-6

Discussion on Experimental Results

6.1 Cutting Tool Wear and Condition

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

Cutting tools may also often fail prematurely, randomly and catastrophically by 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 strength, hot-hardness and fracture toughness. However, in the present investigations with the tool and work material and the machining conditions undertaken, the tool failure mode has been mostly gradual wear. The geometrical pattern of tool wear that is generally observed in turning by carbide insert is schematically shown in Fig. 5.2. Among the aforesaid wears, the principal flank wear (V_B) is the most important because it raises the cutting forces and the related problems. The life of carbide tool, which mostly fail by wearing, is 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. Therefore, attempts are to be made to reduce the rate of growth of flank wear (V_B) in all possible ways without sacrifice in MRR.

Fig.5.3 and Fig 5.4 shows the growths of average principal flank wear, V_B, on the main cutting edge under dry and MQL by vegetable oil conditions. The gradual growth of average principal flank wear, V_B, the predominant parameter to ascertain expiry of tool life, observed under all the environments indicates steady machining without any premature tool failure by chipping, fracturing etc. establishing proper choice of domain of process parameters. Fig.5.3 and Fig 5.4 also clearly shows that average principal flank wear, V_B particularly its rate of growth decreased by MQL by vegetable oil for both type of steels. The cause behind reduction in V_B observed may reasonably be attributed to reduction in the flank temperature by MQL by vegetable oil, which helped in reducing abrasion wear by retaining tool hardness and also adhesion and diffusion types of wear which are highly sensitive to temperature. Because of such reduction in rate of growth of flank wear the tool life would be much higher if MQL is properly applied.

Fig.5.5&Fig5.6 shows that maximum flank wear (V_M) has also decreased sizeably due to proper temperature control under MQL by vegetable oil in turning both type of steels.

Another important tool wear criteria are average auxiliary flank wear, V_S, which governs the surface finish on the job as well as dimensional accuracy. Irregular and higher auxiliary flank wear leads to poor surface finish and dimensional inaccuracy. The growth of average auxiliary flank wear, V_S has been depicted in Fig.5.7& Fig 5.8 The nature of growth of average auxiliary flank wear, V_S matches with that of V_B expectedly. It appears from Fig.5.7& Fig 5.8 that auxiliary flank wear (V_S) has also decreased during MQL by vegetable oil machining.

The pattern and extent of wear that developed at the different surfaces of the tool tips after being used for machining the AISI 9310 and AISI 1040 steel over reasonably long period have been observed under SEM to see the actual effects of different environments on wear of the carbide insert of SNMG configuration. The SEM views of principal and auxiliary flank wear of the worn out insert after 40 minutes of machining under dry and MQL conditions have been shown in Fig.5.9 and Fig.5.10 respectively. The SEM views of principal and auxiliary flank wear of the worn out insert after 45 minutes of machining AISI 9310 under dry and MQL conditions have been Fig.5.11 and Fig.5.12 respectively.

Under all the environments, abrasive scratch marks appeared in the flanks. There have also been some indications of adhesive wear in the insert. Severe groove wear at the flank surfaces were found in insert under dry and wet conditions. Some plastic deformation and micro chipping were found to occur under dry machining. Effective temperature control by MQL by vegetable oil almost reduced the growth of groove wear on the main cutting edge as well as auxiliary cutting edges. Further the figure clearly shows reduced average principal flank wear and average auxiliary flank wear under MQL by vegetable oil condition in both AISI 9310 and AISI 1040 steels.

It is very much clear from these figures that flank wear develop more quickly in mild than in Alloy steel.

6.2 Surface Roughness

The quality of any machined product of given material is generally assessed by dimensional accuracy and surface integrity, which govern the performance and service life of that product. For the present study, only surface finish has been considered for assessment of quality of product under dry and MQL by vegetable oil in machining.

The variation in surface roughness observed with progress of machining of AISI 1040 and AISI 9310 and steel by the SNMG insert at a particular cutting velocity, V_c, feed rate, S_o and depth of cut, t under dry and MQL by vegetable oil conditions of both AISI 1040 and AISI 9310 steel have been in shown in Fig.5.13 and Fig 5.14 respectively. As MQL reduced average auxiliary flank wear and produced no notch wear on auxiliary cutting edge, surface roughness also grew very slowly under MQL conditions. It is previously found that conventionally applied cutting fluid did not reduce tool wear compared to dry machining. It appears from Fig.5.13 and Fig 5.14 that surface roughness grows quite fast under dry machining due to more intensive temperature and stresses at the tool-tips.

It is also found that surface roughness achieved in AISI 1040 steel is better than surface roughness achieved in AISI 9310 steel due to the rate of tool wear progress and difference in the hardness and Chemical composition in those steels. MQL by vegetable oil appeared to be effective in reducing surface roughness. However, it is evident that vegetable oil has very good lubrication and cooling effect which 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.

Chapter-7

Conclusions

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

ii. Vegetable oil as a cutting fluid using MQL method in machining different steels reduces flank wears, which would enable either remarkable improvement in tool life or enhancement of productivity (MRR) allowing higher cutting velocity and feed.

iii. Surface finishes of the machined workpieces improved mainly due to reduction of tool wear and the damage at the tool tip by the application of MQL by vegelable oil.

iv. MQL by vegetable oil shows different effect in different steels. It is more effective in turning alloy steel than mild steel. Because in case of AISI 9310 steel ,the percentage of reduction of flank wears and surface roughness is more than that of AISI 1040 steel when compared with their dry conditions

i. No fire hazards and less smoke formation were observed while turning steels with MQL by Vegetable Oil.

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

MQL by vegetable if properly employed can enable significant improvement in both productivity and product quality and hence overall machining economy even after covering the additional cost of MQL system.

Chapter-8

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