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Environmentally Friendly Machining: Vegetable Based Cutting Fluid

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ABSTRACT

A wide variety of cutting fluids are commercially available in the market. Although, these cutting fluids are beneficial in the industries, their uses are being questioned nowadays as regards to health and environmental issues. To minimize the adverse environmental effects associated with the use of cutting fluids, the hazardous components from their formulations have to be eliminated or reduced. Today to diminish the negative effects associated with cutting fluids, researchers have developed new bio based cutting fluids from various vegetable oils. MQL machining was performed much superior compared to the dry and wet machining due to substantial reduction in cutting zone temperature enabling favourable chip formation and chip-tool interaction, with enhanced the tool life and surface finish. Furthermore, MQL provides environment friendliness (maintaining neat, clean and dry working area, avoiding inconvenience and health hazards due to heat, smoke, fumes, gases, etc. and preventing pollution of the surroundings) and improves the machinability characteristics. This paper presents the effects of minimum quantity lubrication (MQL) by vegetable oil based cutting fluid on the turning performance of AISI 316L stainless steel as compared to completely dry and wet machining in terms of chip-tool interface temperature, chip formation mode, tool wear and surface roughness.

Keywords : *Minimum Quantity Lubrication (MQL), Cutting Fluids, Chip Formation, Surface finish, Metal Removal Rate, grade vegetable oil(coconut oil),compressor, spray nozzle, AISI 316L stainless steel.*

1. INTRODUCTION

Machining is one of the most critical processes in the manufacturing industries which involve a controlled removal of material from the substrate by using a cutting tool. Since machining involves plastic deformation of the workpiece material and friction between tool-chip and tool-workpiece interfaces, lot of energy supplied is converted into heat. During the machining of low strength alloys, this heat generation is less but when ferrous and other high strength alloys are machined, lot of heat is generated which increases with a subsequent increase in the cutting speed. The distribution of heat generated during machining is shown in Fig.1. This heat generated, if not dissipated successfully, may affect the finished surface quality, reduce the tool life and hence overall performance of the process. Thus, although high speed machining is desirable in many cases for higher productivity, the consequences of heat generation needs to be minimized.

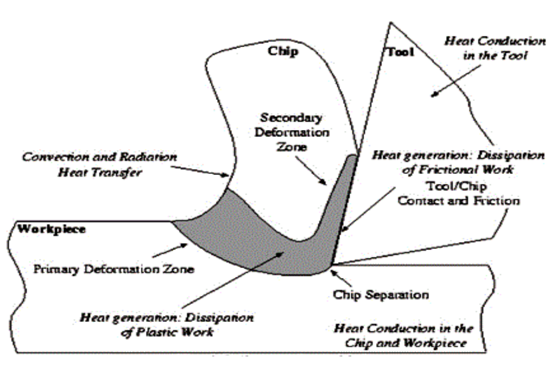

Fig.1: The distribution of heat generated during machining

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Many techniques were evolved for the effective removal of heat from the vicinity of the machining area. Many alternatives were developed to minimize the quantity of cutting fluid used. Some such techniques that came into focus were:

- Dry machining
- Cryogenic cooling
- Coated tools
- Minimum quantity lubrication

But apart from that MQL techniques is use in present senerio.

2. MINIMUM QUANTITY LUBRICATION (M.Q.L)

MQL, also known as "Microlubrication", is the latest techniques of delivering metal cutting to the tool/ work interface. The main aim of minimum quantity lubrication (MQL) is to reap the benefits of cutting fluids without getting affected with the harmful effects of the cutting fluids. It involves the usage of minimal quantity of cutting fluid with a typical flow rate of 5-50 ml/h which is directly applied to the cutting zone thereby avoiding the need of fluid disposal as it happens in flood cooling. Since MQL involves significantly lesser amount of cutting fluid, this phenomenon is popularly referred to as 'near dry machining' or 'micro lubrication' or 'spatter lubrication'.

2.1 Methodology

This method involves the application of an aerosol of highly compressed air (typical pressure of air = 4-6 bar) and cutting fluid (lubricant) through a specially designed nozzle with hole diameter of magnitude 1-2mm. In this method, as the cutting fluid in the form of small droplets of aerosol comes in contact with the heated cutting zone, it evaporates extracting the latent heat from the machining area. Thus, this method involves removal of heat by evaporative transfer rather than convective heat transfer method. Since, evaporative heat transfer method is more efficient in terms of extracting heat and also there is no waste disposal problem, MQL surely has an extra advantage with respect to conventional flood cooling.

There are two methods of mixing air and lubricant in MQL method.

1. Mixing inside the nozzle
2. Mixing outside the nozzle

In the first method, the lubricant and air is mixed just before reaching the nozzle in a mixing chamber. The oil-mist is then supplied through the nozzle at high pressure onto the cutting zone. The oil performs the lubricating function while highly pressurized compressed air performs the cooling action.

In the second method, the mixing of oil and compressed air is done in a separate mixing chamber.

- Study of Working Principle of MQL System
- Problem Formulation & Design of Experiment
- Study the Important Factors for Selecting the Natural Oil as a Feasible Choice
- Study and Setup of Experimental Setup
- Study of Experimental Parameters
- Selection of Machinability Characteristics
- Study of Chip Pattern and Formation Mode
- Measurement of Tool Wear and Surface Roughness.

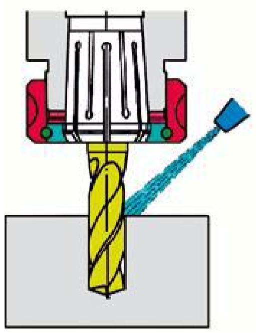

Fig.2 : External lubrication feed

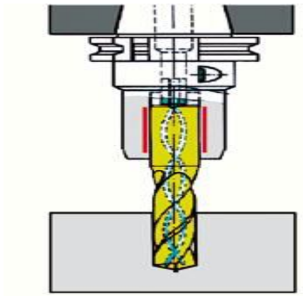

Fig.3 : Internal lubrication feed

2.2 Applications of Minimum Quantity Lubrication

Minimum quantity lubrication is widely applicable in different machining operations such as Turning, Drilling, Milling, Grinding etc.

3. CUTTING FLUID CHARACTERISTICS

Cutting fluids are widely used in machining operations to serve the purpose of reducing thermal deformation by cooling the machining zone and improving the surface finish by providing good lubrication. The main functions of cutting fluids can be summarized as below:

Cutting fluids serve the purpose of cooling the extremely heated cutting zone by taking away some of the heat generated.

- They reduce the coefficient of friction between the tool-chip and tool-workpiece interfaces so as to lower down the heat generated due to frictional effect, thus, lubricating the surfaces.
- They serve the purpose of reducing the tendency of thermal distortion by lowering down the thermal gradient.
- They flush away the chips from the machining zone thereby facilitating the disposal of chips.
- They protect the finished workpiece surface from corrosion and rust formation.

3.1 Properties of Cutting Fluids

The cutting fluids which are to be used must possess the following essential properties which contribute in making them apt for fulfilling their functions.

- A good cutting fluid must have large specific heat capacity and good thermal conductivity.
- It should have low viscosity.
- It should be non toxic, non corrosive and should not react with the tool or workpiece material.
- It should not be very costly and should be easily available.
- It should have high flash point.
- It should be physically and chemically stable.

3.2 Types of cutting fluids

Cutting fluids can be divided into two categories:

- **water-based fluids** -including straight oils and soluble oils
- **oil-based fluids** -including synthetics and semi-synthetics

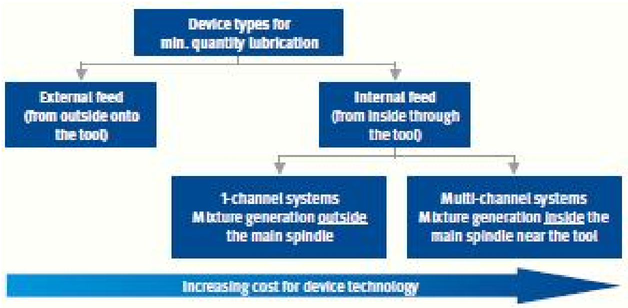

Fig.4: Device types for Minimum Quantity Lubrication

4. LITERATURE SURVEY

The concept of Minimum Quantity Lubrication (MQL) was suggested a decade ago as a mean for addressing the issues of environmental intrusiveness and occupational hazard associated with airborne cutting fluid particles on the shop floor. The minimization of cutting fluid leads to economic benefits by saving lubricant costs.

Bennett and Bennett (1987) found that a source of significant exposure to MWF was inhalation of aerosols. NIOSH recommended no respiratory protection for MWF concentrations of 0.5mg/m3 or less.

Derflinger et al. (1996), on the other hand, describes the drilling of aluminium–silicon alloys as a process where dry cutting is impossible due to the high ductility of the work piece material. Without cooling and lubrication, the chip sticks to the tool and breaks it in a very short time during cutting.

Klocke and Eisenblätter (1997) demonstrated the interest of dry machining and eventually met with success in the field of environmentally friendly manufacturing. However, these can be sometimes less effective when higher machining efficiency, better surface finish quality and severer cutting conditions are required. In these circumstances, semidry operations utilizing very small amounts of cutting lubricants are expected to become a powerful tool and, in fact, they already play a significant role in a number of practical applications. Minimum quantity lubrication (MQL) refers to the use of only a minute amount of cutting fluids typically at a flow rate of 50–500ml/h. Sometimes this concept of minimum quantity lubrication is referred to as near dry lubrication or micro lubrication.

Machado andWallbank (1997) conducted experiments on turning medium carbon steel (AISI 1040) 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 in between 3 and 5ml/min). The mixture was directed onto the rake face of a carbide tool against the chip flow direction. The application of air and soluble oil was able to reduce the consumption of cutting fluid, but it promoted a mist in the environment with problems of odours, bacteria and fungi growth of the overhead flooding system. For this reason, the mixture of air and water was preferred. However, even if the obtained results were encouraging, the system needed yet some development to achieve the required effects in terms of cutting forces, temperature, tool life and surface finish.

MaClure et al. (2001), the concept of MQL has also been suggested since a decade ago as a means of addressing the issues of environmental intrusiveness and occupational hazards associated with the airborne cutting fluid particles on factory shop floors. The minimization of cutting fluid also leads to economic benefits by way of saving lubricant costs and cycle time for cleaning work piece, tool, and machine. However, there has been little investigation of the cutting fluids to be used in MQL machining.

Stabler et al. (2003) suggested the types of fluids not applicable for the minimum quantity lubrication were water mixed cooling lubricants and their concentrates, lubricants with organic chlorine or zinc containing additives, lubricants that have to be marked according to the degree on hazardous materials, and products basing on mineral base oils in the cooling lubricant 3 ppm(parts permillion) benzpyrene.

Dhar et al. (2006) employed MQL machining technique in turning AISI 4340 steel with uncoated carbide tool (SNMM120408). During experimentation, process parameters such as cutting velocity, feed rate and depth of cut were kept constant at 110m/min, 0.16mm/rev and 1.5mm respectively .Water soluble cutting fluid was supplied at flow rate of 60 ml/h and mixed with compressed air prior to being impinged on the cutting zone at a high speed.

Under same cutting conditions, MQL caused a significant reduction in tool wear and surface roughness as compared to dry and wet turning.

This study gives that the Emulsifiers have the function of dispersing the oil in water in order to

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make a stable oil-in-water emulsion. Here the thermal conductivity, kinematic viscosity and pH increased with an increase in the content of emulsifier whereas flash and fire points decreased with an increase in the amount of emulsifier.

5. REQUIRED PARAMETERS

Table-1: Required Parameters

VARIABLES	EXPERIMENT
Machine tool	Lathe machine (15 hp)
Work specimen material	Austenitic stainless steel AISI 316L (C=0.03%, Mn= 2%, P=0.045%, Si= 0.75%, Ni= 14%, S=0.03%, Cr=18%, Mo= 3%, N=0.10%)
Hardness (BHN)	257
Size	$^{\Phi}$100x 710mm
Cutting tool	Uncoated carbide
Working tool geometry	Inclination angle -6 °
	Orthogonal rake angle -6°
	Orthogonal clearance angle 6 °
	Nose radius 0.8mm
Cutting velocity, Vc	223,246,348,483 m/min.
Feed rate , So	0.10,0.13, 0.16, 0.18 mm/rev.
Depth of cut 't'	1.0 mm
Cutting fluid	MQL Condition- food grade vegetable oil
Cutting fluid supply	For MQL cooling- Air- 6 bar
	Flow rate 100ml/h(through external nozzle)

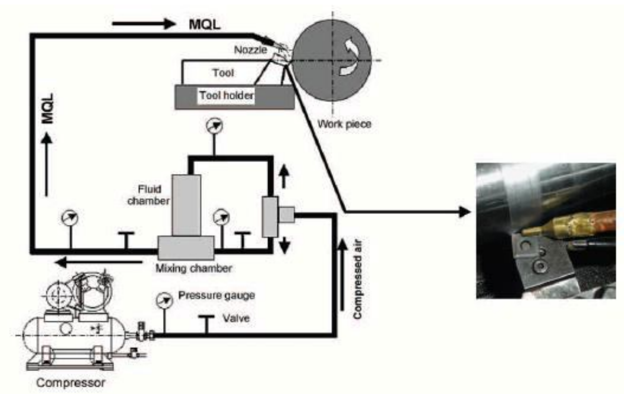

Fig.5: Experimental Setup

6. DESIGN OF EXPERIMENT

Experiments were conducted on plain turning a 100mm diameter and 710mm long rod of Austenitic stainless steel AISI 316L which are commonly used in a powerful and rigid lathe (15hp) at different cutting velocities and feeds under dry and MQL by vegetable oil conditions. These experimental investigations were conducted with a view to explore the role of MQL on the machinability characteristics of that work material mainly in terms of cutting temperature, chip formation, tool wear and surface roughness. The ranges of the cutting velocity (*V*c) and feed rate (*S*0) were selected based on the tool manufacturer's recommendation and industrial practices. Depth of cut was kept fixed to only 1.0mm, which would adequately serve the present purpose. Machining ferrous metals by carbides is a major activity in the machining industries. Machining of steels involves more heat generation for their ductility and production of continuous chips having more intimate and wide chip–tool contact. Again, the cutting temperature increases further with the increase in strength and hardness of the steels for more specific energy requirement. Keeping these facts in view, the commonly used Austenitic stainless steel AISI 316L was considered in this experimental research.

Fig.6: Design of experiment

7. RESULTS

7.1 Effects of MQL On Cutting Temperature

1. Work material: Austenitic stainless steel AISI 316L
2. Cutting tool: uncoated carbide
3. Depth of cut: 1.0mm
4. Feed rate: 0.10mm/rev.

Table-2: Effects of MQL on Cutting Temperature

CUTTING VELOCITY Vc(m/min)	AVERAGE CHIP TOOL INTERFACE TEMPERATURE °C	
		DRY
225	765	815
250	818	900
350	915	965
	965	1045

7.2 Effects of MQL on Chip Formation

1. Work material: Austenitic stainless steel AISI 316L
2. Cutting tool: uncoated carbide
3. Depth of cut: 1.0mm
4. Feed rate: 0.16mm/rev.

Table-3: Effects of MQL on Chip Formation

CUTTING VELOCITY Vc(m/min)	CHIP REDUCTION COEFFICIENT	
	MQL	DRY
240	2.8	3.6
250	2.6	3.25
350	2.3	2.9
450	1.9	2.7

7.3. Effects of MQL on Toolwear

Table-4: Effects of MQL on Toolwear

MACHINING TIME	AVERAGE PRINCIPLE FLANK WEAR Vb	
	MQL	DRY
0	0	0
4	48	20
12	110	40
22	165	60
31	240	72
35	270	202

8. CONTRIBUTION OF THE RESEARCH WORK

The current research work demonstrated and established the effectiveness of machining AISI 316L austenitic stainless steel under MQL with MoS2 powder-mixed cutting fluid. The effect of two different base fluids namely conventional water soluble cutting oil and paraffin oil has also been investigated. Significant reduction obtained in cutting temperature along with decrease in surface roughness, cutting force and chip thickness when MoS2 powder was added to the base fluid clearly exhibited the supremacy of powder- mixed MQL in turning operation. The outcome thus obtained from the current study is expected to be of immense significance for various machining industries.

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9. RECOMMENDATION AND FUTURE SCOPE OF RESEARCH

In practice, demanding production processes (HSC machining) for large-scale mass production have been implemented using process-reliable MQL. For this to be the case it is important that the elements are optimally adjusted to each other. A key objective for the user is to keep the MQL process "easy" to use and initiate. The selected NC program contains all information (optimal interface parameters, lubricant quantity and feed, tool etc.) for the smooth running of the process.

A standard for defining the relevant programs and processes is currently being worked out by a steering committee of industrial companies. This steering committee is composed of experts from companies which have already implemented minimum quantity lubrication in their own production or which, as suppliers, have many years of production system experience in using this technology. The objective of the standardisation is to adapt all commonly used MQL systems to the production process through defined configurations.

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