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Minimum Quantity Lubrication

Nilesh C Ghuge, Dhatrak V.K., Dr.AM.Mahalle,
MCERC Nashik,LIT,Nagpur

Abstract: - *Metal cutting fluids changes the performance of machining operations because of their Lubrication, cooling, and chip flushing functions. In the machining of hardened steel materials, no cutting fluid is applied in the interest of low cutting forces and low environmental impacts. Minimum quantity lubrication (MQL) presents itself as a viable alternative for hard machining with respect to tool wear, heat dissertation, and machined surface quality. This review paper gives comparison of the mechanical performance of minimum quantity lubrication to completely dry lubrication for the turning of hardened bearing-grade steel materials based on experimental measurement of cutting forces, tool temperature, white layer depth, and part finish. This review paper shows that the use of minimum quantity lubrication leads to reduced surface roughness, delayed tool flank wear, and lower cutting temperature, while also having a minimal effect on the cutting forces.*

I. Introduction

Conventional metal working fluid delivery system provide fluids to work zone in volumes which "flood" the work area these fluids are filtered then recirculated through the system.Microlubrication delivery system provides extremely low volumes of fluids to the process. Micro lubrication is also known as MQL or near dry machining.

Minimum quantity lubrication refers to the use of cutting fluids of only a minute amount typically of a flow rate of 50 to 500 ml/hour which is about three to four orders of magnitude lower than the amount commonly used in flood cooling condition, where, for example, up to 10liters of fluid can be dispensed per minute.", It has 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 economical benefits by way of saving lubricant costs and work piece/tool/machine cleaning cycle time

On the other hand, completely dry cutting has been a common industry practice for the machining of hardened steel parts. These parts typically exhibit a very high specific cutting energy. It is observed that completely dry cutting, as compared to flood cutting, lowers the required cutting force and power on the part of the machine tool as a result of increased cutting temperature. However, achievable tool life and part finish often suffer under completely dry condition.

Under these considerations, the concept of minimum quantity lubrication presents itself as a possible solution for hard turning in achieving slow tool wear while maintaining cutting forces/power at reasonable levels, provided that the minimum quantity lubrication parameters can be strategically tuned. The purpose of this research is to study the effects of minimum quantity lubrication condition on the cutting performance of hard turned parts, as compared to completely dry cutting.

The study helps to provide an understanding of the behavior of the tool and the work piece under hard cutting conditions, involving high thermal and mechanical loads. In the study, the minimum quantity lubrication is provided with a spray of air and vegetable oil. During each test, surface roughness, white layer depth, tool wear, cutting forces, and temperature are measured and compared. The following sections describe the experimental set-up, procedure, data, and analysis.

II. Need of MQL system

2.1 The path from wet to dry machining

In many cases the driving force behind the introduction of dry machining is the recognition that today work piece related costs for cooling lubricants can be several times higher than tool costs. Moreover, the handling of cooling lubricants is increasingly causing problems, including the burden they place on employers and the environment. Since there is no need for a cooling lubricant cycle in the value-added process, there is a direct reduction of costs. Experience shows that productivity is significantly improved at the same time: production times are cut by as much as 50% regardless of the production job and choice of tools. Since there is no need to clean work pieces, the process chain is shortened and further costs saved as a result. Internally, a conversion of production processes from wet to dry machining helps to motivate personnel; externally it contributes to a better corporate image. In addition, lawmakers and statutory accident insurance associations are enacting stricter laws and regulations in reaction to the hazards posed by cooling lubricants. For a company that means snot only more responsibility and new obligations vis a vis the personnel but also, and above all, higher costs. Wide scale introduction of dry machining in the production sector makes it possible to avoid the economic and ecological problems entailed by wet machining.

To successfully substitute conventional wet machining with near dry machining, two main issues should be resolved. One is the development of **MQL equipment** which can maintain conventional machining performance. The other is the establishment of methods for **chip removal**. Its aims to combine environmental improvement and production cost savings through research and development of the reduction of cutting oil and the realization of dry machining. Of key importance is unique MQL equipment, technology for mixing inside the spindle, and the use of a vacuum (chips suction) system.

III. Basics of Minimum Quantity lubrication

MQL means Minimum Quantity Lubrication. This is a new machining method that delivers the required minimum quantity of lubricant mixed with air and performs machining through a continuous supply of this oil/air mixture to the tool tip. This method is also called semi dry machining, near dry machining (NDM), and MMKS. This method for machining and the mixture are called MQL. **MQL** makes it possible to reduce the amount of lubricant to nearly zero. [1] [2]

MQL generally uses vegetable oil or ester oil as the cutting fluid. These high-performing oils have excellent lubrication and natural dissolving properties. Furthermore, they are environmentally friendly.

Many advantages are realized through the use of **MQL** and the reduction of cutting oil consumption. These include improvement of the plant environment; improvements in chip recycling, reduction of electricity consumption, increased tool life, a "greener" environment, and a decrease of machine maintenance due to contamination by coolant.

In conventional manufacturing of mass-produced parts that typify automotive parts (engine, transmission, brake, etc.), a large volume of cutting fluid (coolant) is used to improve productivity and machining accuracy. Recently, the negative effects of cutting fluid upon people and the environment have become a serious problem so the reduction of coolant is strongly required.

3.1 Principle of MQL

Minimum-quantity lubrication system lubrication involves a loss or Consumption lubrication, i.e. the lubricant is used up almost completely during processing so that a preparation is not necessary in the cycle. An air current with finely distributed oil drops, so-called aerosol, lubricates the friction spots between the tool and the chips running off in the chip grooves. The minimum-quantity lubrication system assures effective lubrication of cutting processes using smallest amounts of lubricant. The arduous task of cleaning and disposing large amounts of lubricant and cooling lubricant is, if necessary at all, made much easier.

3.2. Types of MQL system [2]

A) Internal minimal quantity Lubrication (MQL)

An aerosol is generated in the MQL equipment's reservoir and fed through the rotating spindle or turret to the tool. With an optimal setting the metered quantity of oil is completely used up without any residue being left.

b)External minimal quantity lubrication (MQL)

Metered lubricant is atomized by compressed air in a spray nozzle. That produces micro droplets that make their way together with the carrier air to the friction point without any mist being formed.

3.3 Design Details [1]

The basic design consists of the following.

1. Aerosol generator and lubricant reservoir
2. Main air valve
3. Control cabinet housing
4. Connections for aerosol lines
5. Plug screw for manual filling
6. Filling level indicator
7. Pressure gauge for interior vessel pressure
8. Pressure gauge for primary pressure
9. Compressed air connection
10. Drain opening or connection for return line to the lubricant
11. reservoir
12. Connection for intake line, for automatic lubricant refill
13. Spy glass for display panel of controller
14. Controller interface
15. Safety valve and Fine filter for compressed air
16.

3.4. Schematic representation of MQL and its working

Figure 1 (a & b) shows schematic diagram of MQL system

This system mainly consist of

1. **Aerosol generator**
2. **Nozzle**
3. **Compressor**

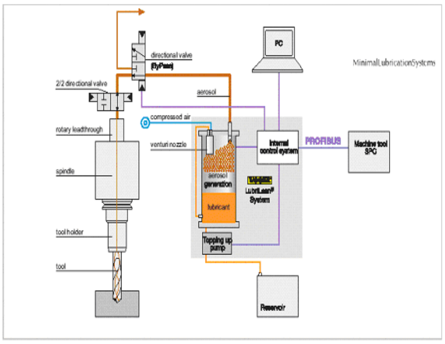

Fig 1(a).Mql System

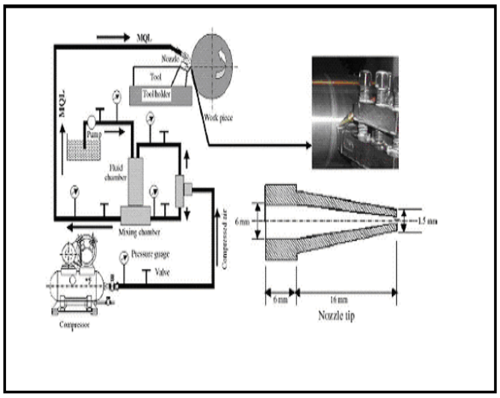

Fig 1(b).Mql System

3.5. Active Principle of Aerosol [1] [2]

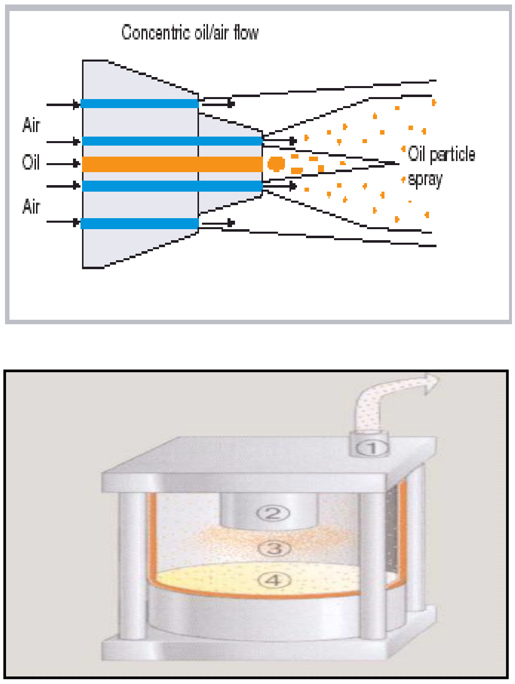

Fig 2. Principle of Aerosol

The MQL system here described here with reference to the size and distribution of the lubricant drops, generates a very homogeneous aerosol with a drop size of approx. 0.5 µm.The oil drops are very light because of their small size, which in turn results in a very low moment of inertia. These small drops of oil can be transported over long stretches through lines and deflections without being deposited due to the moment of inertia. Additionally, the transport of the aerosol through rotating spindles and tools is unproblematic for the minimum-quantity lubrication systems even at very high rotational speeds, since the effect of centrifugal force on the oil drops is very low.

Effective lubrication of the cutting process can be achieved with extremely small amounts of oil. Higher productivity is achieved due to higher cutting speeds and longer tool lives. And there is no need to condition or dispose of cooling lubricants.

3.5.1 How the Aerosol Works

` The size and distribution of the droplets of oil in the aerosol are very homogenous with LubriLean minimal quantity lubrication systems since the aerosol is atomized under controlled conditions that result in physical advantages:

In addition to the high degree of surface wetting, extremely fine particles of lubricant also reach poorly accessible or hidden spots on the work piece .Difficult through feed tasks with deflections of the kind found in the turrets of turning machines can also be handled. Nor does the transport of aerosol to the active site present any problem in the case of milling machines running at speeds of more than20, 000 rpm Lines as long as 20 m from the minimal quantity lubrication system to the machining site are likewise no problem for these installations either .The friction, and thus the transfer of heat from the chip to the tool and work piece, is reduced. Optimal lubrication during removal of the chips in the chip groove not only permits higher machining speeds but also results in a much better work piece surface finish.

A fine aerosol with a homogenous particle size of ~ 0.5 µm is produced in the reservoir from a lubricant and compressed air with a special nozzle system. Thanks to the small particle size, the aerosol passes through the rotating spindles of machining centers or through the winding ducts of turrets on modern turning centers without any demixing taking place en route .Dependable machining is assured by such loss free transport. Modern machining centers with a large number of tools require individual control of the aerosol quantity by stored program control (SPC) of the machine tools. The aerosol

Quantity and composition required for the respective tool and cutting task are set by valves switched with M or H commands from the machine's control system.

Transport of the aerosol through lines as long as 20 m is no problem for LubriLean Digital Super and Vario systems .A ball valve has to be installed directly upstream of the spindle inlet or turret to assure short response times despite long transport routes. A "bypass" system can be optionally integrated in the aerosol feed to achieve shorter response times – as regards the supply of altered quantities of aerosol. The production of aerosol is not stopped thereby during the tool change. The newly required amount is produced instead. The aerosol is directed through a 3/2_way ball valve for this purpose. That makes sure the new quantity of aerosol is available right away when the process starts the aerosol produced during the tool change can be route directly into the exhaust system or – if the system is optionally outfitted with an additional topping up reservoir through a demixing device.

3.5.2 Spray Nozzles

The aerosol required at the process point is produced at the nozzle outlet. The lubricant and required atomizing air are fed through coaxial lines from the minimal quantity lubrication system to the spray nozzle. The lubricating mixture is formed at the Nozzle outlet by the Venturi principle. Carrier air flowing past the oil outlet sweeps the lubricant along with it and turns it into extremely fine lubricant particles. The concentric oil/air flow that results from this special design keeps the jet from expanding and causes the aerosol to be delivered to the process spot with pinpoint accuracy. As a result, contamination of the surroundings with excess aerosol is successfully prevented.

The purpose of spray nozzle is to generate tiny droplet of lubricants in the Desired size and direct them to the lube surface with the help of carrier air the shape and size of lubrication pattern are determined by the shape of and dimensions of individual nozzle openings no oil mist is produced by the internal shape of nozzle the nozzles are designed to assure appropriate floe velocities and trouble free flow the oil and air are fed to the nozzles separately in coaxially tubing system

3.5.3 Compressor

By means of compressed air, the aerosol generated inside the vessel is transported via one or several connected aerosol lines to the supply connection at the machine tool.

3.5.4 Compressed Air Requirements
Requirements Values

Maximum air admission pressure 8 bar
Minimum air admission pressure 4 bar
Compressed air quality class according to ISO 8573-1 5
Maximum particle size 40 µm
Maximum particle density 10 g/m³
Maximum pressure dew point +7 °C
Maximum lubricant concentration 25 g/m³

Main air valve is closed before connecting the MQS system to the compressed air supply.The MQS system has an NG8 coupling socket for hoses with an inside diameter of 7-8 mm for connection to the compressed air supply. For the compressed air to be used, please observe the requirements outlined above. The MQS system can operate with an admission pressure of as low as 4 bar. However, the system reaches its peak performance only with an admission pressure of 8 bar.

IV. Advantages of MQL

4.1Cost Merit

The cost of cutting fluid (coolant) is 3 to 4 times higher than tool cost in production cost of parts for auto mobile.

1. No need for cooling lubricants
2. No need for machine tool
3. components like lubricant
4. filters and conditioning systems
5. No disposal costs for chips and cooling lubricants
6. No need to wash work pieces

4.2Chip Removal

The countermeasure of chip treatment is one of the problems that should be mostly considered in the construction of mass production. A large quantity of coolant is conventionally used for is charging chips outside machine. In order to adopt MQL in mass production, it is necessary to be surely done chip treatment with another method instead of much coolant. HORKOS CORP has solved problems to use the combination of the gravity drop method and the vacuum method (suction method). The followings are examples of chip treatment.

4.3 Improve Productivity

1. Significant reduction of production time (30 _ 50 %)
2. Higher cutting efficiency
3. Tool lives increased by as much as 300%
4. Reliable control of production processes

4.5 Utilize a Technological Advantage

1. Solutions for OEMs and
2. retrofitters
3. Parallel use of wet and dry
4. machining
5. No changes in design of
6. spindle required

7. Experimentation and results

Figure 3 shows the use of a minimum quantity lubrication applicator (Units Lubricator) horizontal lathe (Hardinge T42SP) the coolant used was a triglyceride and propylene glycol ester solution dispensed at a flow rate of 50ml/hour under the nozzle pressure of 20psi. The work piece material is high carbon steel bars hardened to 62 to 64 RHC. The cutting tool used was low content CBN tool (Kennametal KD5625) with rake angle of -6o, chamfer length of 0.12 mm, horn radius of 0.03 mm, and nose radius of 0.8 mm.

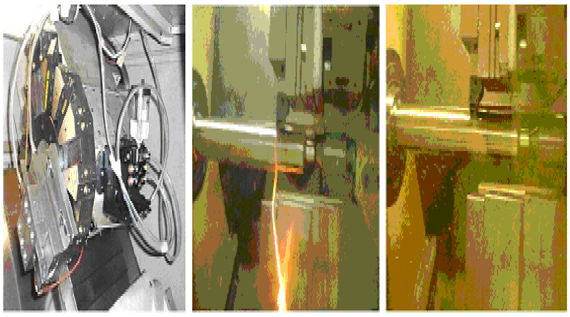

Fig 3.Experimental set up

During machining, cutting forces were measured with a tool post dynamometer This system actually measures the temperature under the insert, at the tip but between the shim and the insert. The temperature (Temp) at the thermocouple location can be related to the temperature (Tc), as measured by inferred imaging method, at the tip of the tool by Temp (t) T (t) = 1/K {Tc (t-c) {
Where k is an attenuation factor with a value on the order of 8, and δ is a time delay often observed to be about 4 sec.

Figure 4 shows the increase of cutting forces with respect to feed. However, the use of Minimum quantity lubrication does not affect the force level in any noticeable way. Therefore, the thermal softening of material does not seem to occur with such a small amount of fluid. The rise of temperature at tool shim corresponding to various feed. The temperature rise is defined as the change of temperature during the first second of machining. The application of minimum quantity lubrication is observed to alleviate the high temperature on chip

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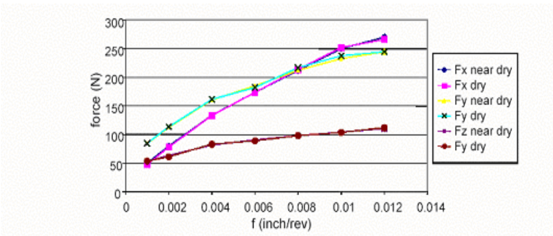

Fig 4. Increase of cutting forces with respect to feed

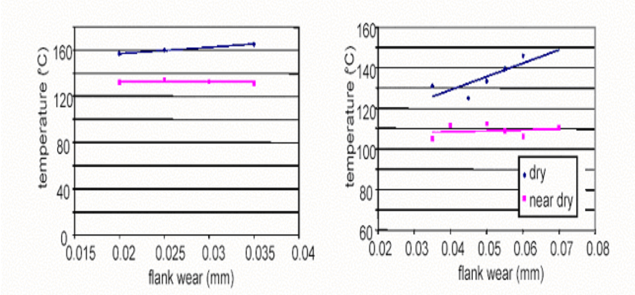

Fig 5.temperature vs flank wear

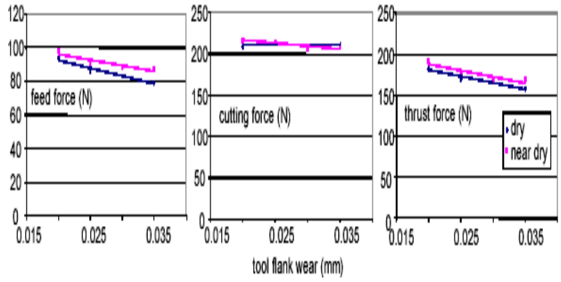

Fig 6.force vs. flank wears up

The resulting surface finishes are shown in Figure 7.Under the depth of cut of 0.012 inch and feed of 0.006 in/rev, the chip formation is smooth with no side flow present, making the feed marks clearly distinguishable. The effect of minimum quantity lubrication is to lower the Ra finish by about 50% with all fresh tools and under the given set of cutting conditions. However, the same amount of finish improvement was not consistently observed when other feed conditions were tested. Generally, the effect of minimum quantity lubrication is more noticeable under stronger – higher feed and deeper cut – conditions. Tests were also performed with certain wear lands on the tool flank. These wear land were naturally developed to various lengths during machining. The purpose of the tests was to evaluate the effect of tool wear on the performance of minimum quantity lubrication as well as assess the resulting tool performance under minimum quantity lubrication. Figure 5 &.6 shows the cutting forces with dry and minimum quantity lubrication conditions under the influence of tool flank wear. Note that the material removal rate was relatively high and the decrease of cutting forces in all feed, tangential, and thrust directions is attributed to the existence of crater wear. The use of minimum quantity lubrication in this case does not lead to noticeable force difference.

Temperatures after two minutes of cutting were measured with tool worn to different Extents. This temperature is not the temperature right at the tool-work piece contact point, but rather the temperature under the tool shim where the thermocouple is located. The tested condition did not permit white layers to take place on the work piece. Fewer than two different cutting conditions, the steady state temperature are to be lower by about 20 to 30 degrees while minimum quantity lubrication is used. Since temperature is an important factor governing the thermal damage on tool, the life of the cutter is expected to change according to lubrication condition Measurements of tool wear was taken after each cut.

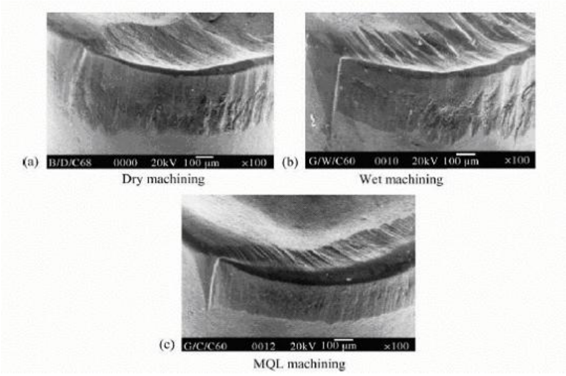

Fig 7.Chip formation

In two different cutting conditions, it is seen that the rate of tool wear is reduced if minimum quantity lubrication is applied. The eventual termination point of the test determines the tool life, which is caused primarily by chipping on the tool rake. The minimum quantity lubrication postponed such chipping so that the flank wear was allowed to progress to a greater length before the tool failed. In terms of machining time, it is further noted that the use of minimum quantity lubrication contributed to the prolonging of tool life by 35% to 50%.

Based on the Taylor's model, cutting tool life (T) can be generally described in term of Cutting velocity as

$$T_C^{\exp(C)\,V} = (2)$$

Tests were performed to confirm the dynamic behavior of temperature and force in Response to minimum quantity lubrication. During testing, the total length of cut (8 inches) along the bar specimen was divided into three consecutive sections. The first section was cut completely dry, the minimum quantity lubrication was applied

at the start of the second section and at the tool entrance into the third section, the minimum

quantity lubrication was turned off so that a dry cutting condition resumes. The steady state temperature drops by about 15% as a result of minimum quantity machining application, while the time it takes to reach such a steady state temperature is on the order of 20 to 30 seconds. The forces exhibit no apparent difference with or without the use of minimum quantity lubrication. These observations are generally consistent with other steady state testing results.

VI. Conclusion

In this review paper an experimental study has been performed to examine the effect of minimum quantity .The resulting surface roughness, no noticeable difference can be concluded with the use of near-dry over completely dry condition. However, the improvement of surface finish can be more obviously felt by near-dry machining under greater depths of cut and feeds. In the context of steady-state cutting temperature, a 10 to 30% reduction is consistently observed when minimum quantity lubrication condition is applied as opposed to completely dry. It is expected to be a result of increase in the evaporative heat transfer at the cutting zone.

The cutting forces not changed significantly.

The thermal softening effect of work piece in completely dry machining condition is not overwhelming; therefore, the benefit of using completely dry over minimum quantity lubrication is not readily justified. There is a significant increase of tool life – over 30% -- by minimum quantity lubrication over a wide range of cutting conditions. This effect is in close coupling to the reduction of cutting temperature. It can thus be concluded that the use of cutting fluid at minute amounts can potentially protect the tool while holding the cutting forces relatively unchanged in comparison to completely dry cutting. Other machining performance issues in terms of chip flushing and environmental consciousness have not been included in this study. Further research in these directions is suggested.

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