EFFECT OF MINIMUM QUANTITY LUBRICATION (MQL) ON GRINDING: A REVIEW

Prashant Rakholiya[1], Harshil Savsani[2], Ayanesh Joshi[3]
A. D. Patel Institute of Technology India
Prashantrakholiya1995@gmail.com[1], harshilsavsani9196@gmail.com[2]

Abstract
In metal working industry, coolant-lubricants are widely used in large quantities which results in high consumption of lubricant, high cost and ill effect on the environment. Due to this reason various lubrication approaches have evolved, improved and are optimized in aspects such as high efficiency, emission reduction, ecological friendly and energy conservation for various machining processes. This paper presents the review of the various research papers published on use of MQL method for grinding process. This paper also highlights various recommendations for future research regarding MQL in grinding.
Keywords: Grinding, Minimum Quantity Lubrication, Near Dry Machining, Surface Roughness.

I. Introduction

Nowadays, manufacturing industries are the chief wealth producing sectors where machining plays a vital role. In machining, most of the energy supplied to the machine tool is converted into heat. When different materials are machined, increase in machining speed will increase the temperature and decrease the tool strength which leads to tool failure. For higher productivity, high cutting speed is desirable but due to high temperature, faster tool wear will limit the cutting speed. Thus temperature at the cutting zone needs to be cooled down. To deal with the heat generated during machining, cutting fluids have been the conventional choice in the industries.

Flood cooling technique is widely used in industries for application of this cutting fluids but it has some downsides such as; equipment to recirculate, filter, test and treat coolant are required, it affects the workshop environment, reachability of flood coolant at the required cutting zone is less and it is also observed that use of cutting fluids badly affects human health and the environment both during its use and during its disposal. Due to this reason, use of this fluids in excess amount should be avoided. [1]Apart from conventional methods of cooling, various other cooling techniques developed in recent years are cryogenic cooling, minimum quantity lubrication (MQL), solid lubricants, high pressure coolants, compressed air/gas coolants etc. [2]Lawal et al. examined different cooling techniques using vegetable oil-based lubricants and observed that the MQL technique stands out among the others.

II. Minimum Quantity Lubrication

A. Abbreviations and Acronyms

- MQL – Minimum Quantity Lubrication
- PAO – Poly-α-olefin
- CBN – Cubic Boron Nitride

B. Minimum Quantity Lubrication Technique

Minimum quantity lubrication (MQL), as its name implies, uses the smallest amount of metal working fluid to achieve lubrication during machining processes. Objective behind MQL is to improve surface finish, improve product quality, higher productivity, minimal environmental impact, lower operator health issues, reduced water and greenhouse gas emission, and reduced energy consumption, which result in lower overall costs. [3]In MQL technique, lubricant is mixed with compressed air in very small amount to form aerosol, which is sprayed in the cutting zone at high pressure with the use of nozzle.

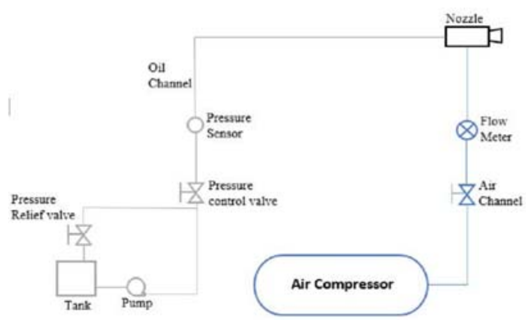

Figure 1. Simple line diagram of MQL setup

IV. Grinding using MQL

Grinding is an abrasive machining process that uses a grinding wheel as the cutting tool. Grinding is widely used as the finishing machining process for components that requires smooth surfaces and precise tolerances. Large fluid delivery and cooling systems are evident in production plants. From both environmental and economical point of view, there are critical needs to reduce the use of cutting fluids in grinding process, and so MQL is a promising solution. [4]The performance of MQL method in grinding is governed by process parameters, work material, tool material and the lubricant used.

A. Review of MQL on grinding

During the material removal in grinding process, the abrasives slide and plunge against the workpiece. Due to this, temperature of cutting zone increases and specific energy is high. So in order to improve the process efficiency, lubrication is an important requirement of grinding fluids along with the removal of chips and cooling of the grinding zone. This fluids are harmful to the health of the operator. Also the cost of this fluids are not feasible enough. Thus MQL can be used as a good alternative to this processes compared to conventional methods of lubrication.

Grinding ability of hardened stainless steel and aluminum alloy was studied using MQL, dry and flood cooling techniques. Vegetable oil and synthetic ester MQL oils were used to test 5 types of corundum wheels and 1 SiC wheel in terms of surface temperature, grinding force and surface topography. [5]It was observed that synthetic ester MQL oil has better performance as compared to the vegetable based MQL oils. It was also observed that use of soft wheels gave better grinding ability while performing MQL cooling. Also due to chip loading effect on the grinding wheel, low surface roughness was obtained for grinding Aluminum based alloys while using vegetable oil based MQL as compared to the high surface roughness obtained when ester based additives were used.

Mohsen Emami et al. evaluated the performance of four types of lubricants namely synthetic, hydrocracked, vegetable and mineral oil during MQL grinding of Al_2O_3 engineering ceramic. [6]Synthetic oil PAO leads to lower specific energy and is preferred in rough grinding whereas hydrocracked based oil results in high surface quality and is preferred in finish grinding. Lubrication via MQL not only affects the cutting forces, specific energy and surface roughness in Al_2O_3 ceramic grinding, but can also diminish environmental hazards of cutting fluids by the incorporation of ecological friendly oils.

Cong Mao et al. performed another study in which, water based Al_2O_3 Nano fluid was applied to grinding process with MQL approach for its excellent convection heat transfer and thermal conductivity properties on hardened AISI 52100 steel. Results were compared to wet, dry and pure water MQL grinding. [7]It was observed that water based Al_2O_3 Nano fluid MQL grinding can reduce the grinding temperature, decrease the grinding forces, improve the ground surface morphology and reduce the surface roughness in comparison to pure water MQL grinding.

P.H.Lee et al. performed a series of experiments using a small vitrified CBN grinding wheel and tool steel workpiece for Nano-diamond and Nano Al_2O_3 particles as nanofluid additives. [8]It was observed that Nano-diamond particles could be more effective than nano-Al_2O_3 particles for reducing grinding force magnitude. Nano-Al_2O_3 particles seemed to be more effective than Nano-diamond particles for reducing surface roughness, especially in the case of larger size.

Zhang Dongkun et al. performed experiments on four cooling lubrication conditions (dry grinding, MQL, flood and Nano-particle jet MQL) by using MoS_2 and ZrO_2 as Nano-particles in Nano-particle jet MQL. [9]It was observed that specific grinding energy in MoS_2 Nano-particle jet MQL was 32.7 J/mm^3, which was 8.22% and 10.39% lower than that of other two Nano-particle. The effects of 1%, 2% and 3% MoS_2 Nano-particle volume concentrations on lubrication performance and surface quality was investigated. It was found that best lubrication performance and the optimal workpiece surface quality were obtained with 2% MoS_2 nanoparticle volume concentration.

Rabiei F. et al. performed experiments to study the effect of mechanical properties of steel on performance of MQL technique. Two soft and ductile steels (CK45 & S305) and two hard and brittle steels (HSS & 100Cr6) have been investigated using dry, conventional flood and MQL technique. [10]MQL can reduce normal grinding force in hard steels while in soft steels normal grinding force are more than flood conventional lubrication. Surface roughness and quality are better in MQL technique for hard steels while in case of soft steels, they are poor in comparison to flood cooling or even dry condition.

Influence of different grinding wheel materials and different coolants on the performance of the grinding process where studied in terms of grinding force and surface finish. [11]Wheel materials like resin bond corundum, vitrified bond corundum and vitrified bond were used to perform many experiments for dry, MQL and flood cooling methods in which eleven different types of coolants were used. It was observed that performance did not change due to change in wheel material but chip loading effect reduced.

To find the effect of minimum quantity lubrication parameters on the performances of grinding, Balan et al. has studied Inconel 751. [12]It was analyzed that MQL lead to a decreases in surface roughness, grinding forces and temperature in the cutting zone. Also it was noticed that minimum grinding force and surface roughness can be achieved by increasing the air pressure and the amount of fluid in MQL.

In another study of grinding the steel, the impact of feed, depth of cut, wheel speed and work hardness on the surface properties of hardened steel and soft steel was studied for optimization of the results. It was noticed that when MQL was used for grinding the 100Cr6 hardened steel, the surface finish obtained was better along with improved quality in comparison to flood cooling. But in case of grinding 42CrMo4 soft steel, surface roughness observed was poor compared to flood cooling. [13]Thus for obtaining accurate results, factors such as wheel velocity, work feed, and depth of cut should also be varied along with MQL parameters.

[14]Alves et al. have studied the behavior of minimum quantity lubrication for developing the methodology of fluid by assembly of nozzle. Pulverized vegetable oil was used in MQL for grinding of steel. It was observed that surface integrity and diametrical tool wear improved while using MQL.

Minimum quantity lubrication results to a lowered tangential force which in turn results in to better slipping of the grains at the interface of work and tool due to which better surface finish and lower grinding force are obtained. Also while using MQL, the removal of metal occurs due to shearing or fracturing, while in case of non-conventional methods, removal of metal took place due to shearing of fracture. [15]Three grades of steel-M2, EN8 and EN31 were examined by Barczak et al. for both MQL and conventional methods in which surface roughness, grinding torque, power and specific forces were evaluated. It was observed that results obtained by MQL were better compared to flood cooling method, but the cost factor observed was on the higher side.

Oliviera et al. performed MQL grinding using a vitrified CBN wheel on AISI 4340 tempered and quenched steel. An air jet focusing was used on the cutting zone which helps in removal of coolant and chips from the cutting zone. Factors like surface roughness, diametrical wheel wear and metallographic images of the ground surface and subsurface were analyzed. [16]It was observed that by implementing the air jet technique consumption of cutting fluid reduces.

In another study, Tawakoli T. et al. performed MQL grinding of 100Cr6 hardened steel with oil mist to know the influence of oil mist parameters on MQL in grinding process.[17]It was observed that MQL oil mist effectively penetrates the boundary layer flow around the grinding wheel, when spray nozzle is positioned angularly towards the wheel (10^0-20^0 to the workpiece surface). In MQL grinding, surface roughness and tangential forces were highest when the oil mist was supplied to the workpiece surface. Grinding wheels with coarser grains and high porosity have less active grains and smaller wear flat area, which make them the best choice for MQL in grinding process.

Hadad M. et al. performed an experiment in which conventional Al_2O_3 and super abrasive CBN wheel were used on 100Cr3 hardened steel workpiece to study the effects of cooling on the leading edge, trailing edge and grinding zone using MQL/flood environment. [18]It was observed that despite the good lubrication of MQL technique in grinding process, it cannot meet the grinding cooling requirements comparing with flood grinding with regard to the temperature response curves obtained in the analytical modelling and the experiments carried out with MQL. This is the main reason limiting the widespread application of MQL in grinding.3

B. Conclusion

MQL process when used for grinding is successful as compared to the conventional methods. Improved surface properties and low tool wear are obtained in MQL process due to high MRR and low friction. So proper selection of cutting parameters will result in highly economical machining process in MQL technique as compared to other conventional technique.

C. Recommendation for future work

There are many ways by which use of MQL technique in grinding can be studied and improved further.

[10]Rabiei F. et al. found that grinding force and surface roughness in MQL is more effective in case of grinding hardened steel as compared to soft steel. But [15]Barczak et al. concluded that MQL is more effective for soft materials as compared to hard materials. Thus further research is required to solve this argument.

Very few researchers have studied the optimization of MQL operating parameters like spray distance, nozzle orientation angle, Fluid flow rate, air pressure etc. Performance characteristics of MQL can be improved by optimizing the above mentioned parameters individually or in combination. Thus further research is required in this direction.

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