Is MQL an efficient and sustainable option? - A Review

Pariniti Singh, Dr. Chinmaya Prasad Padhy

Abstract— Metal Working fluid (MWF) used in industries has varied usages, such as lubrication, cooling, and chip flushing function etc. during cutting and machining operation. Although of its positive uses, there are many adverse effects also seen not only on human life but also on environmental pollution. Because of them, some alternatives have been sought to avoid or to minimize the use of metal cutting fluid during machining operation. In this paper, an effort has been made to study and summarize the relevant literatures made available on the risk associated with Metal Working Fluid (MWF) and to qualify the application of Minimum Quantity Lubrication (MQL) as a sustainable option in curtailing hazardous impact and a cost effective method for machining operation.

Index Terms— Cutting, Machining, Metal working fluid (MWF), Minimum quantity lubrication (MQL), Sustainable, Environment, and Hazardous.

1 INTRODUCTION

Metal Working Fluid (MWF) or Cutting Fluid is widely used for friction reduction, cooling the chip-work piece interface (thus, enhancing tool life), carrying away the swarf reducing the cutting forces and protecting the work piece during machining and other manufacturing processes (see Fig. 1). Metal Working fluids have extensive use and its addition to machining process results in high productivity and high quality machining operations (see Fig. 2).

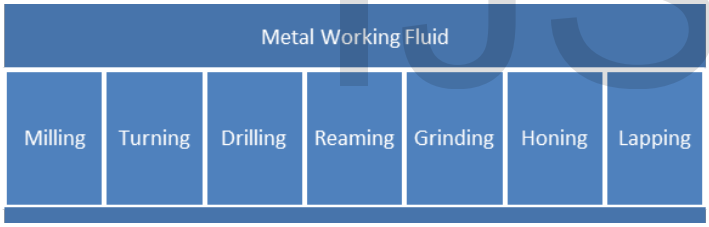

Fig 1.Metal Working Fluid a requirement of Machining

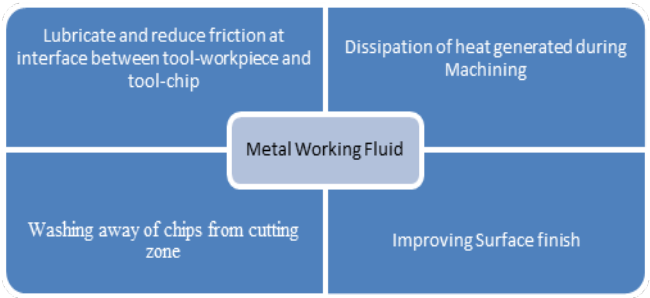

Fig2. Effects of Metal Working Fluid in Machining

Usually, in conventional cutting and machining processes, thousands of gallons of MWFs must be transported, filtered, chilled and finally dispensed. The reprocessing and disposal of these fluids result in very high costs, still other associated costs necessary for cleaning and drying of the chip prior to disposal or recycling, which basically increases the energy costs for manufacturing. Also, it is to be noted down that on an average 10-15 percent of workpiece-related costs are used as cooling lubricant costs. So, one of the key energy efficiency is the use of very economical means of lubrication

With rapid growth in industrialization, addition of toxic or dangerous substances in environment is also increasing, which is adversely affecting not only nature, but also human life. Causes of pollution are of wide range and their effects are severe. Some of the causes of pollution are manufacturing, the waste in form of exhaust gases, volatile organic matter, chemicals and particulates causes dangerous effects on ecosystem. Therefore, issues like energy efficiency, costs and sustainability are becoming increasingly important.

As it has been seen, Metal Working Fluids (MWFs) usage is summarized as important to manufacturing industries, however, they also have negative ecological issue and adverse effect on human health, viz., skin problems, respiratory diseases, hazardous etc(see Fig 3). In these applications, MWFs have sufficient evidence of causing carcinogenicity to humans. National Institute for Occupational Safety and Health (NIOSH) has conducted more than 70 onsite health hazard evaluations (HHEs) of facilities with occupational exposure to metal working fluids and mineral oil aerosols.

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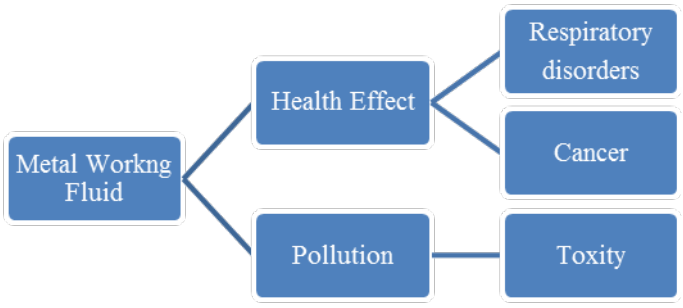

Fig3. Adverse Effects Associated with use of Metal Working Fluid

There are various guidelines and acts given by Occupational safety and health administration (OSHA), according to which prevention steps are to be adapted for providing a workplace free from hazards. In traditional cooling by flooded coolant, additional equipments are required to reticulate, filter and treating it again to ensure the required viability. Also, cost of MWFs is nearly as high as 15% of the total cost to produce a part (see Fig. 4). With these issues, researchers are prompted to innovate new techniques for reducing its usage or else trying to find some alternatives against these harmful fluids. The concept of minimum quantity lubrication (MQL) has a big role in minimizing metal working fluid usage and also adds up economic benefits by saving lubricant cost and work piece/tool/machine cleaning cycle time. Also, Minimum Quantity Lubrication /Micro Lubrication provides substantial reduction in tool wear, which enhances tool life ,surface finish accompanied by reduction in cutting zone temperature enabling favorable chip formation and chip tool interaction. MQL provides environmental friendliness by maintaining neat and clean work area and avoiding other health hazards due to heat, smoke fumes and gases, thus preventing surrounding pollution.

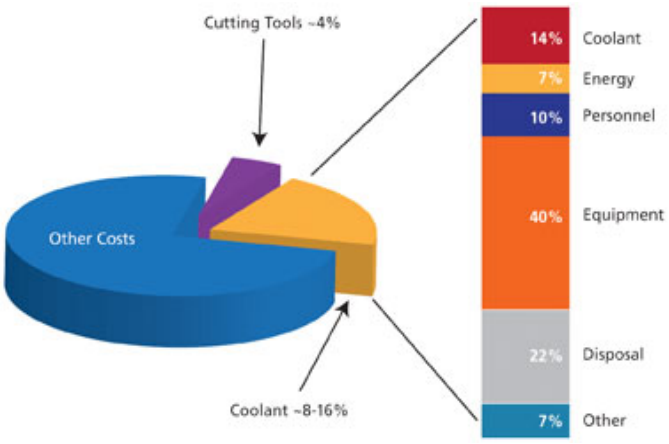

Fig4. Various cost associated with use of Traditional MWF (MAG Americas)

2 Novel Approaches to Reduction of Cutting Fluid Use

Elimination or reduction in amount of cutting fluid in some processes can be done without compromising performance measures. In these cases, operations can be performed to satisfaction in a more economically feasible and environmentally responsible manner. The following strategies can be implemented.

2.1 Dry Machining

Dry machining refers to machining without using cutting fluids. Replacing the functions of MWF during dry machining has proven challenging. This is largely due to the fact that MWFs perform multiple functions simultaneously. These include lubricating the work piece and tool, conducting heat from the cutting zone, inhibiting corrosion of the work piece, cleaning the work piece, and flushing chips from the cutting zone. The relative importance of these MWF functions depends on the operation, work piece and tool material, cutting speed, feed rate, and depth of cut. The absence of MWF can have negative impacts on machining. The absence of cooling and lubrication leads to a temperature increase due to friction. This causes accelerated tool wear, residual stresses between machined parts, dimensional errors, poor surface finish, and metal chip build-up on both the tool and work piece. The absence of active chip removal from the cutting zone also leads to high temperatures and tool failure.

2.2 Minimum Quantity Lubrication

Minimum Quantity Lubrication (MQL) also referred as "Minimal Quantity Lubrication", "Near-Dry Machining" "NDM", "Micro-Lubrication", and "Micro-Dosing". Minimum Quantity Lubrication (MQL) is an alternative for use of traditional metal working fluids (MWFs) in machining process.

MQL is defined as process of applying a minute amount of high-quality lubricant directly to the cutting tool/work piece interface rather than using large quantity of flooded lubricant/coolant (see Fig. 5).

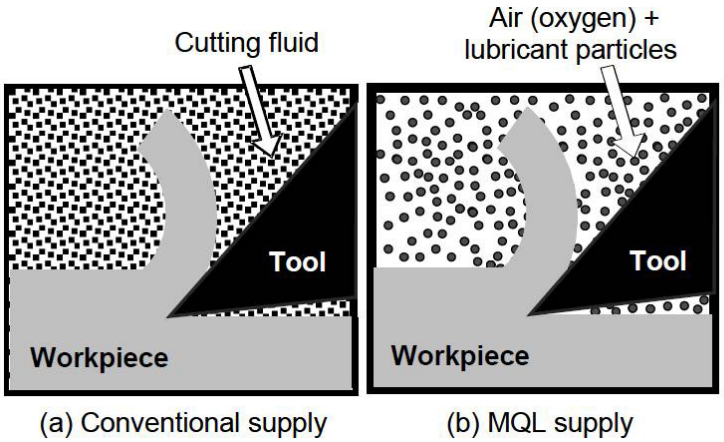

Fig. 5 Schematic illustration of the difference between (a) Conventional supply and (b) MQL Supply [1]

The goal of an MQL system is to mix and deliver a precise amount of aerosol. The diameter of the aerosol particles is maintained with a precise tolerance to maintain good wetting and lubrication properties. It minimizes the adverse effect on environment by reducing fluid usage and eliminating the need of coolant and its disposal (see Fig. 6).

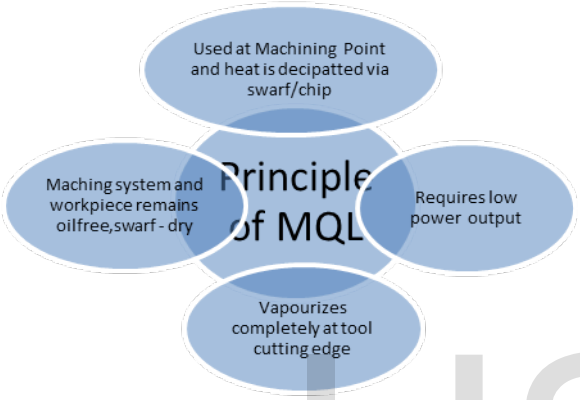

Fig6. Principle of Minimum Quantity Lubrication

A MQL lubricant transmits majority of the heat from friction to chip and exits in the interface and expels itself along with chip. This process of lubrication and expelling of heat keeps the tool cooler and also reduces tool wear. With MQL adoption it is seen that tool life enhances twice as compared to traditional process. With MQL, parts generally do not need cleaning before secondary operation. As lubricant gets consumed, no disposal is required and no extra equipment for recirculation is needed. In addition with these advantages, MQL implementation adds up to cost reduction. In a study, Ford saw around 13% reduction in overall cost after the implementation of MQL.

The MQL technique consists of misting small quantity of lubricant, at flow rate of 50 to 500 ml/hour, in air flowing towards the machining zone [2] [3]. The lubricant is sprayed with the help of external supply nozzle. The quantity of coolant used in MQL is about 3-4orders of magnitude lower as compared to flood cooling condition [4]. MQL is self consuming lubrication, i.e., the amount of lubricant applied gets evaporated at the point of application. This evaporation, in concurrence with the compressed air stream, cools the work piece. The remaining heat is expelled through chips formed [5]. The chips, work piece and tool are dry and hence work place remains clean as compared to traditional machining process. MQL techniques represent another growing class of environmentally adapted lubricants (EALs) have been defined in the European Union as lubricants that have high biodegradability and low toxicity with performance equal to or better than conventional alternatives. MQL typically involves sprays of compressed air and a small amount of oil to provide the function of a MWF without the large volumes of aqueous waste. Researchers are focused on developing new approaches that extend the reach of MQL to more intense machining processes.

2.3 Minimum Quantity Lubrication with Nano fluids

Nano Working Fluid is one the novel concept where nanoparticles are suspended in conventional working fluid, developed to meet properties like cooling, lubrication and other machining challenges. Their nanometer size allows them to enter into the contact are like molecules. They are immediately efficient even at room temperatures. Various types of nano particles can be used to prepare nano lubricants, including polymers, metals, organic and inorganic materials. Researches have shown that with the use of nano fluids there is considerable increase in heat transfer coefficient [6-7]. Nano fluids are produced by distribution of solid nano particles in a base fluid like water, oil, ethylene glycol and many more. Addition of nano partices alters wetability, lubricating property and convective heat transfer coefficient [8].

3 Application of MQL in various Machining Processes:

As mentioned above there are many manufacturing areas having requirement of Metal Working Fluid, Below are few discussions on implementation of Minimum quantity Lubrication as an alternative solution for the same.

3.1 Grinding Process:

Grinding is a very common material removal process. The grinding process is associated with high cutting force, high wear out of grinding wheel as well as surface and sub-surface damage. Bin Shen [9], experimented application of Water-based Al2O3 and diamond nanofluids for MQL on cast iron and also comparison was made between dry machining and MQL application on machining on cast iron, and conclusion was made that MQL grinding significantly reduces the grinding temperature. Various other parameters like surface roughness, G-ratio, grinding temperature and grinding forces were also studied. Investigation clearly showed that application of MQL significantly improves machining process in all the above aspects. Yamin Shao, Steven Y. Liang [10], in their paper, they presented an analytical model to predict the forces under MQL grinding conditions were developed and validated. The model is comprised of boundary lubrication model, single grit force analysis and wheel topography model. The effect of boundary lubrication on friction coefficient in the grinding zone was addressed. Analysis draws relationships between intermediate parameters in friction coefficient in boundary lubrication governed by the force developed between the wheel and the work piece and the contact geometry.

Surface grinding of AISI 1045 work piece with aluminum oxide wheel under various process parameter combinations were pursued, and the predicted grinding forces were compared to experimental measurements and reasonable agreements in the context of magnitudes and trends were found.

3.2 Milling Operation

Milling is the most common form of machining, a material removal process, which can create a variety of features on a part by cutting away the unwanted material.Alper Uysala , Furkan Demirena , Erhan Altana[11], In this paper Martensitic stainless steel material having hardness, strength and wear resistant properties and owing to which has multiple uses like in aerospace, automotive, hydroelectric engines, cutlery, defense, ball bearings, sporting equipment industry, dental and surgical instruments etc which is machined using cutting fluid traditionally is machined using MQL technique. It uses two different amounts of nanofluids (Nano MoS2 particles added to the vegetable cutting fluid at weight fraction of 1%) – pressure air mist supplied by MQL system 20 ml/h and 40 ml/h was considered , minimum tool wear and surface roughness value was obtained in nano MQL milling at 40 ml/h MQL flow rate. It is found after experimentation that the MQL application reduced the tool wear and surface roughness. S. Thamizhmanii, Rosli, S.Hasan [12], In his research he took Inconel 718 nickle based material which is difficult to be machined. Milling process with vegetable oil by minimum quantity lubrication (MQL) was experimented on in a vertical milling machine with super hard cobalt tool. The various cutting parameters like cutting speed, feed rate and constant depth of cut were studied with MQL application of 12.5, 25 and 37.5 milliliters per hour (ml/hr). MQL technique offer better results than by dry cutting in terms of surface roughness. Also MQL did not contribute much in milling with low cutting speeds. Super alloy tools show good performance on surface roughness at 30 m/min by MQL than dry milling. There was improvement in surface roughness at 37.5 ml/ hour MQL supply than 12.5 and 25 ml per hour. The flank wear by 37.5 ml / hour by MQL was low. The tool life was increased by 43.75 % by MQL than dry cutting.

3.3 Turning Operation

Turning is an external cutting process in which a non rotator tool bit follows helical path while work piece rotates.Ali,Dhar & Dey [13], This paper investigates the effect of MQL by cutting oil in turning of medium carbon steel by uncoated insert SNMG-120408 on chip thickness ratio, cutting temperature, cutting force, surface roughness and tool wear on medium carbon steel. It was concluded that MQL reduces the formation of built up edges along with improving aforesaid machinability characters. G. Globočki Lakić [14], This paper discusses the effect of using of MQL technique in Turning operation on carbon steel C45E. Machining parameter like depth of cut, feed rate and cutting speed were adjusted to semi-machining and roughing. Comparison was made using flooded lubrication and MQL lubrication technique. Further Analysis was done via regression analysis and artificial neural network. Experiment showed that cutting forces, intensity of tool wear and surface roughness can be md by use of MQL significantly.

4 Application of Nano cutting fluids:

M. Amrita [15], In this paper nano cutting fuid by including 0.3 wt% of nano particle and its stability was checked. These nano inclusions were applied at the flow rate of 10 ml per minute while performing turning operation under constant cutting conditions. Performance of cutting fluid was evaluated by measuring cutting force, cutting temperature near chip tool interface, tool wear and surface roughness for each turn. Also comparison was done between Dry and MQL application with emulsifier oil without inclusions. It was seen that MQL with inclusions of nano particles in emulsifier oil is significantly better than Dry and Wet machining. S. Khandekar [16], In this Experiment nano-cutting fluid is developed by mixing self-synthesized Al2O3 nano particles into the conventional cutting fluid. The wettability of water, conventional cutting fluid, and nanocutting fluids is measured to demonstrate the better wettability characteristics of nano-cutting fluids compared to other two fluids.It was investigated that adding 1% Al2O3 nanoparticles (by volume) to the conventional cutting fluid greatly enhances its wettability and lubricating characteristics compared to pure water and conventional cutting fluid.

5 Conclusion

Metalworking fluids (MWFs) have wide range of functions that makes them essential part of manufacturing industry. However, MWFs also have inherent environmental and health liabilities associated with them that are of concern to the industry. Considering the various researches and developments in the field of Metal Working Fluid (MWF), it is clearly evident that Minimum Quantity Lubrication (MQL) is a major development in machining process. Reduction in use of Metal Working Fluid has led to sufficient advancements in machining technology. In mass production where production rate is high use of Metal Working Fluid being a point of concern, in those conditions MQL adoption significantly acts as an economic cost effective technology and a property enhancer for Metal Working Fluid. The main findings indicate that MQL showed a significant reduction in use and hence reducing toxicities along with reduction in cutting temperature, cutting tool wear, cutting force and surface roughness rate as compared to traditional and dry machining processes. Thus, we can conclude that MQL system should not be seen only as "shortener cost" for machining centers, but definitely an improvement of the manufacturing process faster and more efficient, besides being an excellent contributor to the environment.

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