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COMPARATIVE STUDY OF MINIMUM QUANTITY LUBRICATION FOR MACHINING PROCESS

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ABSTRACT

At present, Modern machining processes face cost pressures and have expectation of high quality. To remain competitive a company must frequently identify cost reduction opportunities in production and continuously improve the quality of the product. Hence, there is a vast discussion about the use of lubricants in machining. Industry and research institutions are eager to find the ways to reduce the use of coolant/lubricants because of economic and ecological reasons. Here, literatures relevant to Minimum Quantity Lubrication (MQL) have been studied. Of which we have mainly focused on the effect on the performance, characteristics and machining by use of MQL compared to other type of lubrication processes. From this we had found that MQL is relatively more in favor to reduce wear, tear and friction on the particular conditions.

Keywords: *MQL, Dry machining, HPJAM, Production and Tribology.*

1. Introduction

Machining, clean up the plant and “go green” all at same time. Over the years, tribology plays a significant role to energy saving and resource conservation through reducing friction, wear and tear. Tribology is a combination of two Greek words “Tribo” means rubbing and “Logy” means knowledge. It will help to increase life of the machine component [1]. Figure 1 show an industry can use economically-friendly production processes, which leads to a better image in the market.

Due to the vital role of tribology in metal machining process the coolants and lubrications applied in different process is quite different. Cutting oils are essential for proper machining due to their cooling and lubricating capability which enables to work effectively against the shearing at the time of chip formation and tool-workpiece friction zone. Dry cutting, which utilize no cutting fluid is contributing to the solution of environment problem, but on the other hand it has disadvantage of lower efficiency and production precision. The ASME committee on lubrication in their report says the magnitude for the energy conversation that can be potential be obtained in the four major areas i.e. power generation, industrial process, road transportation and turbo-machinery [2]. According to manufacturing statics the total cost for transportation, maintenance and disposal of the coolant or lubrication represent approximate 8 to 20 % of the total production cost depending upon the machining process, work piece structure and production location [3].

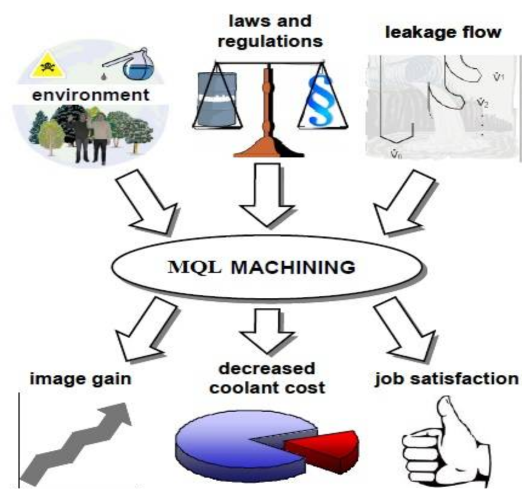

Fig. 1 Benefits of MQL machining

A typical large automobile metal processing utilizes more than 2.28 million liter of metal working fluid per year and more than 1.14 million liters of straight oil per year [4]. Figure 2 shows the cost distribution of the cooling fluids in automotive machining industries.

In this regards, we should make afford to move to Minimum Quantity Lubrication (MQL) which is environmentally friendly, cost effective and also helps to clean the manufacturing industry. The process of applying minimum amount of qualitative lubricant directly between the tool- workpiece interfaces is known as MQL. According to one study “Ford” saw 13%

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decrease in overall cost after implementation of MQL [5]. This was due to reduction in cutting fluid, cost of coolant handling, maintenance and increase in machine up time and cutting tool life.

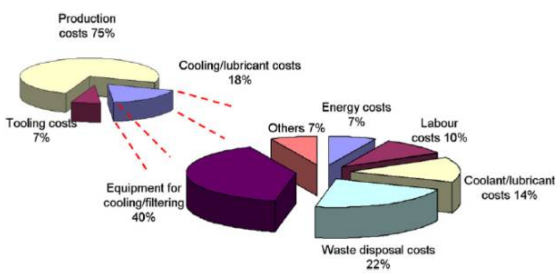

Fig.2 The cost distribution of the cooling fluids in automotive machining industries [18]

MQL combined with tribology directly contributes to the reduction of carbon emission. Tribology plays major role in cutting which combined with MQL makes key technology to achieve the sustainable, low carbon society "eco-machining" [6].

2. Machining using MQL

Better quality of the machined surface can be achieved by the MQL machining in comparison with dry machining. The temperatures of cutting zone are relatively smaller with MQL machining that means better stability and less tool wear during cutting process [7]. Figure 3 indicates the difference between (a) Conventional supply and (b) MQL supply. In MQL cutting, the reactivity of the lubricant ester is increased by atmospheric oxygen, leading to the formation of effective lubricating film [8].

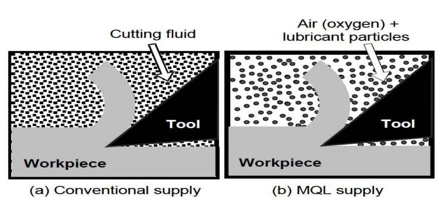

Fig. 3 Schematic illustration of the difference between (a) Conventional supply and (b) MQL supply [21]

During a wide range of material-process combinations, MQL and dry machining operations are required as shown in Table 1 [9]. Milling and turning operations involving different materials can usually be performed completely dry due to high capacity for resistance to thermal wear.

Table 1. Application areas for dry machining and minimum quantity lubrication [9]

Material	Aluminum		Steel		Cast iron
Process	**Cast Alloy**	**Wrought alloy**	**high-alloyed bearing steel**	**Free cutting, quench and tempered steel**	**GG20 to GGG70**
Drilling	MQL	MQL	MQL	MQL dry	MQL dry
Reaming	MQL	MQL	MQL	MQL	MQL
Tapping	MQL	MQL	MQL	MQL	MQL
Thread forming	MQL	MQL	MQL	MQL	MQL
Deep hole drilling	MQL	MQL	---	MQL	MQL
Milling	MQL dry	MQL	Dry	dry	dry
Turing	MQL	MQL dry	Dry	dry	dry
Turing	---	MQL dry	Dry	dry	Dry
Gear milling	---	---	Dry	dry	Dry
Sawing	MQL	MQL	MQL	MQL	MQL
Broaching	---	---	MQL	dry	Dry

Machining using coolants or cutting fluid leads to environmental pollution and various skin diseases, because these fluids consists of sulfur (S), phosphorus (P), chlorine (CL) and other external additives[10]. Further, the cost of treating the waste liquid is high and the treatment itself is the source of the air and earth pollution. Machining process which is not completely dry but uses a minimum amount of qualitative lubrication or cooling oil are referred to "near dry" machining, in Japan this is commonly referred as "semi-dry" machining [2]. Typical flow rate of the MQL cutting fluid is about 50 to 500 ml/hour which is about three or four order of magnitude lower than commonly used flood cooling condition [11]. The holes obtained by drilling using MQL system shows either better or similar quality than with flood of abundant soluble oil [12].

3. MQL Lubricant Characteristics

MQL is consumption lubrication; much of the lubrication applied to tool chip interface is evaporated at the point of application due to the compressed air stream, which cools the workpiece. MQL requires good lubrication properties. Lubricants like, synthetic easter oil and vegetable oil display high biodegradability depending on their combined molecular structures of acids and alcohols. These are used with flow rate between 0.2 and 500 ml/hr and air pressure is roughly 5 bars [13]. It does not recirculate through the coolant delivery system. Due to unsaturated bonds, vegetable oils are usually liquids at room temperature. The workpiece, tool and chip remain nearly dry in an ideally adjusted MQL system.

Table 2. Characteristics of MQL Fluids [15]

Synthetic esters	Fatty alcohols
Chemically modified vegetable oils	Long-chained alcohols made from natural raw materials or from mineral oils
- good biodegradeability - low level of hazard to water - toxicologically harmless	
- high flash and boiling point with low viscosity - very good lubrication properties - good corrosion resistance - inferior cooling properties - vaporizes with residuals	- low flash and boiling point, comparatively high viscosity - poor lubrication properties - better heat removal due to evaporation heat - little residuals

Source: Fuchs Petrolub AG

MQL generates a significant quantity of mist equated to flood cooling. To manage the fine mist, mist collection and filtering is required. Using vegetable based lubricants, machining is safe for both operator and the environment [14]. Synthetic esters and fatty alcohols are the media most commonly used in MQL applications (Table 2). The medium selected depends on the type of supply, the cutting material and type of operation [15].

4. Performance of MQL on different machining

A study in international journal of machine tools and manufacturing found that on hardened steel with a carbide end mill, flood cooling resulted in shortest tool life due to severe thermal crack while the use of MQL led to best performance.

Machining on workpiece material St52-3 steel Using MAL observed less cutting force up to 25% depending on settings of MQL parameters [7]. When oils/coolants are used during machining, emphasis is more on the good lubrication properties. Their function is to reduce adhesion and friction between tool-chip interfaces. As a result, heat generated will be reduced. Subsequently, the tool-workpiece produce less heat compare to dry machining (Fig. 4) [16].

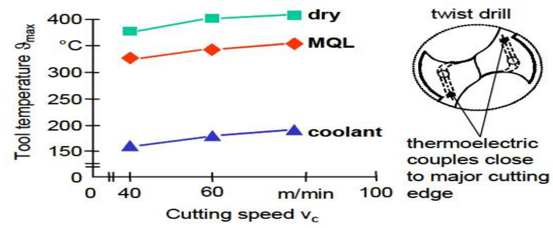

Fig. 4 Tool temperatures in drilling with different cooling lubricants [16]

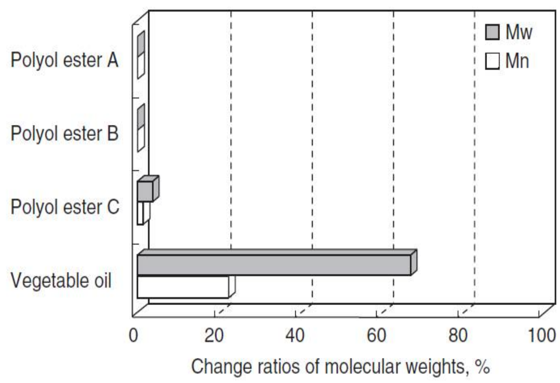

Fig. 5 Change of molecular weight by oxidative degradation [2]

The primary performance of the cutting fluid is cutting performance followed by safety and work related performance like skin disease. Oils used for the MQL machining, must be environmental friendly oil mist partials that can easily escape the plant and must having the secondary performance like safety and biodegradability [6]. MQL machining oil must have characteristics of highly oxidation stability [17]. Toshiki [2] has done the experiment to find oxidative degradation on aluminum plate using three different oils and vegetable oil. The plates are heated for 168 hours at 70 0C and then measure the molecular weight after oil oxidative degradation as shown in figure 5.

Sanchez et al. [18] experimented on grinding using hybrid MQL-CO2 machining figure 6 shows the schematic of the proposed grinding system. The work material is taken as AISI D2 commonly used for the metal forming tools and 400 mm diameter CBL46I6V489 used for the experimentation using different parameters. They concluded that the control of the thickness of the frozen oil layer if too thick will increase the grinding force to accommodate the problem the flow rate of CO_2 at 40 l/min will give the good result.

Ali et al. [19] performed the turning of medium carbon steel by uncoated carbide insert using MQL. They measured the chip thickness ratio, cutting temperature, cutting force, tool wear and surface roughness for the following cutting conditions.

Experiment performed on C45E workpiece, shows the results for tool wear on flank faces for HPJAM, MQL and conventional cooling and lubrication techniques (figure 7). MQL and conventional techniques show almost the same values of tool wear, about T = 8 min, while HPJAM had a four-times longer tool life [20]. The same surface roughness can be obtained in all three cooling and lubrication techniques. In HPJAM, feed and passive cutting forces are 5 to 10% lower than with MQL and conventional flooding.

The higher value of feed force is due to the amount of chip stuck on the nose of the tool using MQL and diamond coat. The diamond coated drill, did not present any advantage when compared to the uncoated K10 insert [14].

5. Summary and Conclusion

Dry machining operations, mainly applied in high-volume, large-scale industries, like automotive manufacturing, still require improved solution; MQL will support and ultimately result in the expansion of these solutions to small and medium-sized manufacturers. The performance of the process, (in terms of forces, tool wear and quality of holes), when using MQL, similar to that obtained when using a high amount of soluble oil, with both, coated and uncoated drills. This proves the possibility of using this in the drilling process of aluminum–silicon alloys.

A MQL technology that represents cost saving and improves the overall performance of cutting operations related to cooling lubrication, dry machining. The use of MQL leads to reduced delayed tool flank wear, lower cutting temperature and surface roughness, also minimum effect on the cutting forces. Using MQL on tool rake has no difference on tool life compare to dry conditions, but when MQL is applied to the tool flank, it can increase tool life.

The cooling action with MQL is reduced compared to the conventional coolant, which leads to no thermal damage on the workpiece. MQL will reduce the Fluid Pump Power (FPP) which will reduce overall cost of the production. Use of MQL shows results relatively more in favor to reduce wear, tear and friction on the particular conditions.

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