Influence of minimal quantity lubrication (MQL) technique in achining evolution: A review and applications

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Abstract
Metal working fluids (MWFs) are one of the types of lubricants, which are extensively used in machining operations. Most of the MWFs are mineral oil based fluids. Due to their advantages, the consumption of MWFs is increasing in machining industry. Mineral, synthetic and semi-synthetic MWFs involve in the ecological cycle with air, soil and water and their toxicity effects damages the ecosystem. Vegetable oil lubricants are potential substitutes for mineral oil not only because they are renewable raw materials but also because they are biodegradable and non-toxic. Currently, there is a wide-scale evaluation of the use of metal working fluids (MWFs) in machining. Industries are looking for ways to reduce the amount of lubricants in metal removing operations due to the ecological and economical aspects. By implementing near-dry machining or a minimal quantity of lubrication (MQL), MWFs consumption can be reduced. The MQL technique involves the application of a small quantity of lubricant dispensed to the tool–work piece interface by compressed air flow. This paper gives a review on the mechanical performance of minimum quantity lubrication compared to completely dry and flood lubrication for various machining operations.

1. Introduction

Material cutting also known as machining is one of the most used techniques for producing different components. In the machining processes a cutting tool removes material from a work piece of a less resistant material [1]. During machining there is often relative motion between the tool and work piece. The temperature developed during cutting as the result of heat is mainly dependent on the contact between the tool and chip, the amount of cutting forces and the friction between the tool and chip. Almost all the heat energy developed is transferred into the cutting tool and cut work piece material, while a portion of it is dissipated through the chip [2]. So, in high-speed cutting, the large fluctuation of cutting temperature could cause thermal cracks on the cutting edge and subsequently leads to failure of a cutting tool due to edge fracture [3]. Various machining force like cutting forces and trust force are developed during machining, which also cause impact on tool and work piece. These forces gradually increase as the tool wear increases. Tool wear and work surface quality are one of the most important economical impact to be taken into consideration while cutting. It is necessary to improve tool life and work surface roughness by minimizing the tool wear and optimizing all the cutting parameters and factors such as depth of cut, cutting velocity, feed rate, cutting fluids and cutting fluids application [4]. In machining great quantities of coolants and lubricants are supplied to avoid thermal damages of the component, to reduce the friction between tool and work piece and to transport the cutting chips out of the contact zone and out of the machine tool. Nevertheless, cooling lubricants are often regarded as a supporting media that is just necessary, but not important. In many cases the cooling system is based on the assumption that the cutting process is supported better by using plenty of lubrication [5]. Conservation of materials and energy is becoming a very important issue. The main cause of energy loss in a mechanical system is the friction but this can be reduced by lubrication. Thus, it is very important to improve the lubrication properties [6]. The cutting fluids play a very important role in machining. The cutting fluids are used in machining processes to improve the characteristics of tribological processes, which are always present on the contact surfaces between tool and work pieces [7]. As concerned with lubrication, the load applied and the machining conditions, which characterize the cut, suggest that it is difficult to continuously lubricate the cutting area by fluid film lubrication. So for lubrication, it is necessary to use lubricant that can chemically react with the work piece and tool material to generate chemical compounds that allow the lubrication of the cutting surface [8].

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Various methods of lubrication are:

1. Hand application: This type of application cannot be used in mass production because it is not easy to apply the cutting fluid continuously at work tool interface. It guarantees a low level of lubrication, cooling and chip removal [9].
2. Flood application: This application is widely used in various manufacturing industries. It guarantees a very good level of lubrication, cooling and chip removing [8].
3. Minimal quantity lubrication (MQL): In the case of minimum quantity lubrication, the quantity of the applied lubricant is reduced to a minimum. In MQL a very small lubricant flow (ml/h instead of l/min) is used. In this type the lubricant is directly sprayed on the cutting area by a very fine jet of air and oil mixture. It gives a good level of lubrication, but the cooling action is small and the chip removal mechanism is obtained by the air flow used to spread the lubricant.

2. Metal Working Fluids

Metalworking fluids (MWF's) are one of the types of lubricants, which are widely used in machining operations. These are mainly classified into four categories: straight, water soluble, synthetic and semi synthetic. Most of the MWF's are mineral oil-based fluids but synthetic are water based solutions of organic and contain no mineral oil [10]. Generally speaking, the cutting fluid applied in the machining process is considered to act as cooling and lubricating agent, hence the cutting temperature can be reduced and the tool life and machined surface finish can be improved [11]. It also helps in carrying away the heat and debris produced during machining. Due to their advantages, the consumption of MWF's is increasing in machining industry. It is reported that the European Union alone consumes approximately 320,000 tonnes per year of MWF's out of which at least two-thirds need to be disposed [12]. However, the use of metal working fluids in machining process has caused some problems such as high cost, pollution, and hazards to operator's health. When inappropriately handled, cutting fluids may damage soil and water resources, causing serious loss to the environment. Therefore, the handling and disposal of cutting fluids must obey rigid rules of environmental protection [4]. Now days, there is a large-scale evaluation of the use of MWF's in machining. Industries are looking for ways to reduce the amount of lubricants in metal removing operations. The reasons for this is the high percentage of fluid costs in the overall manufacturing costs (reaching 17% in some cases), ecological and legal demands and human health among others [13]. Some alternatives has been sought to minimize or even avoid the use of cutting fluid in machining operations. Some of these alternatives are dry machining and machining with minimum quantity lubrication (MQL). MQL is a method that enables reducing the amount of cutting fluids. MQL consists of a mixture of pressurized air and oil micro droplets applied directly into the interface between the tool and the chip. In this cooling and lubrication technology, the lubricating function is ensured by the oil and the cooling function mainly accomplish by the compressed air [14].

3. Minimum Quantity Lubrication

In order to alleviate the environmental and economical impacts, minimum quantity lubrication (MQL) was addressed as an alternative to the conventional flood cooling application a decade ago [15], [16]. It also provides an alternative for machining operations in which dry machining is not applicable especially where machining efficiency and/or high surface quality are of more interest. MQL refers to the use of only a minute amount of cutting fluids typically at flow rate of 50–500ml/h [17]. Sometimes this concept of minimum quantity lubrication is referred to as near dry lubrication or micro-lubrication [18]. In many cases, through the introduction of MQL systems that act based on the principle of total use, without residues, applying lubricant flows from 5 ml/h up to a maximum of 500 ml/h at a pressure from 2 to 8 bar [19].

Heinemann et al. [20] investigated the effect of minimum quantity lubricant on tool life in drilling processes. The cutting fluid flow rate was 18ml/h. It was found that a continuous supply of minimum quantity lubricant conveyed a longer tool life while a discontinuous supply of lubricant resulted in a reduction of tool life. Machado and Wallbank [21] conducted an experiment on turning medium carbon steel (AISI 1040) using lubricant amounting to 200–300 ml/hr, which were applied in a fast flowing air stream of 0.2 MPa. Surface finish, chip thickness and force variation were all affected beneficially compared to those obtained by the flood coolant flow of 5200 ml/min. Tawakoli et al. [22] have investigated an MQL grinding or near dry grinding (NDG) system. In this system, an air–oil mixture called an aerosol is fed into the wheel-work zone. Compared to dry grinding, MQL grinding substantially enhances cutting performance in terms of increasing wheel life and improving the quality of the ground part. In the grinding of 100Cr6 hardened steel by Al2O3 grinding wheel, the surface roughness of ground part was lower than that in flood coolant system. However, in MQL grinding of 42CrMo4 soft steel, the surface roughness was higher than that in flood coolant system. In MQL grinding the cutting forces were lower than the dry and flood coolant systems. The wheel life was the best in MQL systems.

A cutting fluid for MQL should be selected not only on the basis of primary characteristics i.e. cutting performance but also of its secondary characteristics, such as biodegradability, oxidation stability, and storage stability. Those processes, in which the friction and adhesion play a dominant role, generally require the usage of minimal quantities of fluids [23]. In MQL machining, a small jet of lubricant is delivered with compressed air at the tool work interface. The jet of air and oil mixture acts as lubricant and coolant to decrease the cutting temperature and reduce the tool wear. It also flushes off the debris immediately before adhesion on work piece, so as to improve surface roughness. MQL machining can be successfully applied without affecting the machining process results, such as surface roughness, tool life and cutting power [24], [25]. The minimization of cutting fluid leads to economical benefits by way of saving lubricant costs, disposal cost and cycle time for cleaning work piece, tool and reduce the impact concerned with environment & operator health . However, there has been little investigation of the cutting fluids to be used in MQL machining. . Minimum quantity lubrication is now of great interest and actually, they meet with success in the field of environmentally friendly manufacturing [26].

MQL systems:

The coolant with MQL can be supplied in two different ways:

(a) Systems with external supply

In case of external supply, the minimum quantity is supplied to the tool or the required point via a nozzle which is installed in the machining area of the machine. Fig 1. Shows the schematic diagram of MQL system [27].

(b) Systems with internal supply

The internal feeding of the MQL medium is done through the machine spindle, the tool holding system, and the tool directly on the cutting edge. This allows an optimum moistening of the involved components at the point of application. The group of MQL systems with internal supply is divided into one-channel and two-channel MQL systems. In case of the one-channel systems, the aerosol is mixed outside the spindle, whereby the lubricant of a two-channel system is mixed directly inside the spindle.

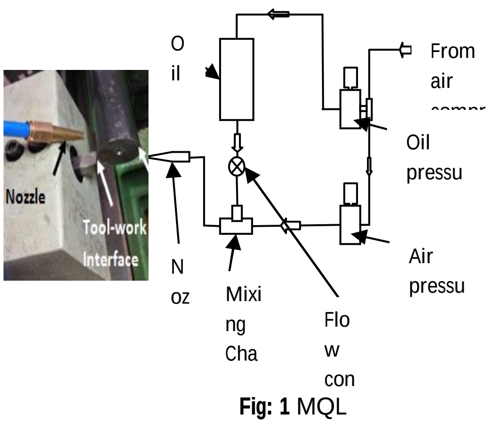

Fig: 1. Schematic view of MQL unit [27]

4. Studies on Minimum Quantity Lubrication

In a study by Thamizhmanii et al. [28], milling operation was performed on Inconel 718 steel. The end milling cutter used was super hard cobalt tool having four flutes. . The value of the cutting velocity, feed rate and depth of cut were 10, 20, 30 m/min, 0.15 mm/tooth and 0.40 mm, respectively. The MQL flow was 12.5 ml/hr, 25 ml/hr and 37.5 ml/hr. The lubricant used was vegetable sunflower seed oil used for cooking purposes. The experiments were conducted under dry and MQL conditions with same operating parameters. It was observed that MQL technique offered better results than by dry cutting in terms of surface roughness. MQL does not contribute any significant results when milling with low cutting speeds. 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.

Priarone et al. [29], investigated the influence of different lubrication strategies (wet, dry and MQL) on machining performances during milling and turning of gamma titanium aluminides. Milling tests were performed by using 8-mm diameter Silmax TiAlN coated and chamfered end-mills. Axial and radial depth of cut were selected to 0.3 mm, the feed was fixed to 0.08 mm/tooth, and the cutting speed was selected to 25, 50 and 100 m/min. Longitudinal external turning operations were carried by using 4 µm multilayer coated tungsten carbide inserts. The cutting speed ranged from 25 to 50 m/min, the feed from 0.1 to 0.3 mm/rev, and the depth of cut from 0.3 to 0.7 mm. Under the chosen cutting conditions, It was observed that in milling, the tool life under MQL conditions was improved as a consequence of the friction reduction. In turning, wet cutting was the best choice for reducing the tool wear. On the other hand, MQL was allows to obtain the best surface quality results in turning.

Kedare et al. [30], milling operation was performed on Mild Steel of 15HRC. Uncoated HSS having four flutes was used as end milling cutter. The experiment was carried out at three cutting speeds viz: 160, 225, 300 rpm, at constant feed rate and three depth of cuts 0.1, 0.2, and 0.3 mm. The end milling was performed under the Minimum Quantity Lubrication condition and conventional flooded lubrication. The fluid was supplied by the MQL system during the experiment 900-1000ml/h at 5 bars pressure. It was resulted that the cutting performance of MQL machining was better than that of conventional machining with flood cutting fluid supply because MQL provides the benefits mainly by reducing the cutting temperature. Surface roughness value of MQL was always less than flood cutting at all cutting speeds. The minimum surface roughness value of 0.95µm was taken with medium cutting speed, 225 RPM.

Nam et al. [31] investigated the effect of nanofluid in drilling on Aluminium 6061. Paraffin and vegetable oils were as used for base fluids, and the nano-diamond particles having 30 nm diameter were added. A micro-drill used in the experiments was an uncoated carbide twist drill, which had the diameter of 200 µm. There were 7 experimental runs according to cutting fluids and nano-diamond concentration. It is observed that pure and nanofluid MQL significantly increases the number of drilled holes with the single micro-drill. Further it is observed that nano-diamond volumetric concentration of 1% in the case of the paraffin oil and that of 2% in the case of the vegetable oil was most effective for the reductions in drilling torques and thrust forces. The nano-diamond particles could effectively prevent chips from being adhered to the micro-drill and played an important role to eliminate burrs and chips during the micro-drilling process.

5. Conclusions

There is enough literature which clearly reveals that MQL system provides better performance than dry machining. So MQL is found to be promising alternative for flooded and dry machining due to their environmental friendly characteristics. These researches show that the flood condition can be replaced by the MQL condition, thus alleviating pollution and improving health and safety.. MQL nozzle position should be at optimum and at desired angle to achieve better results. MQL technique also shows favourable cost reduction due to reduced cost of cutting fluid management. There is additional cost involved in the equipment for MQL. However, factors such as types of work piece material, machining process, cutting tool material and machining conditions still remain critical variables in determining the performance ability of MQL technique.

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