A Short Review on Machining with Ultrasonic MQL Method

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Abstract Cutting fluids are required in huge amount in the modern machining methods. Cutting fluids are needed for providing lubrication as well as cooling the workpiece during machining. Cutting fluids are made of mineral oils and have many drawbacks including many health hazards and environment impact. Various other methods of cutting fluid delivery are being tested in order to reduce the effects of cutting fluids in machining. One such method is minimum quantity lubrication. Many researchers have shown the effectiveness of MQL over the conventional flood method. However, the MQL method has drawbacks in terms of heat carrying capacity. In order to increase the effectiveness of the MQL method, many advanced methods are being tested for improving the cooling efficiency of the MQL method. One of the methods is ultrasonic method. This method is currently in nascent stages and is being researched upon as a viable alternative to the conventional MQL method. This paper describes this hybrid delivery method in machining.

Keywords Green · Manufacturing · Minimum · Quantity · Lubrication · Ultrasonic · Nanoparticle

1 Introduction

1.1 MQL

MQL stands for minimum quantity lubrication. It is being used as an alternate to the conventional flood method of machining in the manufacturing industries. The

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benefits it draws are use of very little quantity of lubricant, thereby saving costs associated with using huge quantity of lubricant and associated hazards.

MQL or minimum quantity lubrication is slowly gaining attention from researchers worldwide due to its better lubrication properties and considerably low quantity of cutting fluid [1–5]. MQL has many advantages like it increases tool life and surface finish [6–13]. A typical MQL involves use of high-pressure liquid from 2-bar pressure to 5-bar pressure and lubricant in atomized form as shown in Fig. 1. The atomized lubricant is in the range of microns and in combination with the high pressure air is able to penetrate the cutting zone effectively [3, 14, 15]. Machining using MQL method thus provides better lubricity than the conventional flood cooling method. MQL typically uses 50–200 ml/h lubricant. An MQL setup consists of a spray nozzle in which the atomized lubricant is mixed either internally or externally depending upon the type of configuration used [16, 17]. Researchers have tested MQL method in different machining methods and have found it to be better than the conventional flood delivery method of cutting fluid delivery. MQL is delivered into the cutting zones as shown in Fig. 2.

Fig. 1 Typical MQL setup [18]

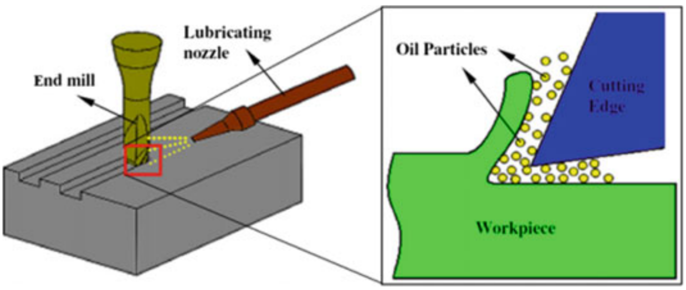

Fig. 2 MQL delivery into cutting zone [19]

2 Ultrasonic MQL

Although MQL has proved to be better than the conventional method, researchers have found that combining the MQL method with some other methods like cold air MQL, cryogenic gas, electrically charging the lubricant has performed better than the conventional MQL method itself [20–26]. One such emerging and promising research is ultrasonic MQL or UMQL. The ultrasonic MQL method actually combines three methods—first is the MQL itself, i.e., atomized lubricant, second is the nanoparticles mixed in the lubricant, and third is the ultrasonic mixing mechanism. The result of these triple parts is an efficient lubricity during machining with a constant homogenous delivery of cutting fluid in to the cutting zone. It has been shown that addition of nanoparticles increase the lubricity of a lubricant. However, it is difficult to keep the nanoparticles dispersed in the lubricant [27–29].

2.1 Application of UMQL

The nanoparticles have a tendency to agglomerate and form lumps within the lubricant bulk. Thus, without proper dispersion of the nanoparticles the whole process will get rendered useless. Thus, it is important to keep the nanoparticles dispersed in the lubricant for an effective fluid delivery process [30–33]. If the nanoparticles agglomerate together, there will be time patches where the lubricant is delivered without nanoparticles and there will be instances where lumps are delivered into the machining zone which will eventually be unable to reach the cutting zone thus failing the whole process. Emulsifiers are used for this purpose [34]. An emulsifier is a chemical compound which makes the dispersion of the nanoparticles in the lubricant easy and for a long time. However, addition of emulsifiers in the lubricant has shown to affect the properties of the nanoparticles in the lubricant. Another way of tackling this problem is employing a mechanism that can keep the nanoparticles dispersed in the lubricant. Ultrasonic dispersion is one such method in which the nanoparticles [35–39]. This paper considers the latest developments in the ultrasonic method with nanoparticles. Ultrasonic MQL has been used in grinding operation mostly. For efficiently utilizing in other operations, it has to be properly setup. Secondly, nanoparticles are costly affair and are lost during machining, so proper care has to be taken for the toxicity effects of nanoparticles on human.

In an attempt to increase the thermal efficiency of the MQL method, Rabiei et al. [40] used water-based nanoparticles in ultrasonic. They employed six different nanoparticles like oxides of titanium, silicon, aluminum, copper, nickel, and multi-walled carbon nanotube in grinding. From the experimental results, it was observed that there was a reduction of 20 and 24.6% in the grinding force when compared to grinding done without any lubricant or coolant. Also, a superior surface finish was achieved without any visible surface defect and damage. Also, no plastic deformation or side flow defect was observed which indicate good lubrication during machining.

Interestingly, the type of chip obtained with MQL ultrasonic grinding was similar to that obtained with the flood method of lubrication which points to the fact that both these methods are similar in terms of machining quality.

Huang et al. [41] tried to improvise the conventional machining process by using nanoparticles in the cutting fluid and also amalgamating MQL with ultrasonic dispersion. Nanoparticles being solid powders have e tendency to agglomerate in water and cause lumping problems which decreases their performance. An effective way is to use an emulsifier to keep the nanoparticles suspended in the solution. However, use of emulsifier increases the cost and can also affect the performance of the nanoparticles. Hence, ultrasonic dispersion method was utilized to keep the nanoparticles suspended for a homogenous solution of cutting fluid. In machining mold steel with this method, the experimental results showed that agglomeration of the nanoparticles was reduced to a very large extent. Also, low grinding forces were achieved with this method in comparison to MQL method alone. This hybrid method also showed lower temperature rise and excellent surface finish than the conventional MQL method without nanoparticles and conventional MQL method with nanoparticles.

Ni et al. [42] used ultrasonic vibration assisted with the conventional MQL machining method in machining titanium alloy. Introduction of the lubricant during the ultrasonic friction between mating surfaces of the tool and workpiece caused increased lubrication. From the experimental results, it was found that the combined method of ultrasonic vibration and MQL method caused reduction in tool wear to a very large extent. On further analyzing the surface of the tool, it was found that the major cause of tool failure was fracture of the surface upon impact which was visible on the surface. From the results, it can be concluded that the combined method of ultrasonic with MQL is a better way of machining titanium alloy and can also enhance the tool life considerably.

Helmy et al. [43] used ultrasonic method of machining combined with MQL method in machining of composite laminates at different machining parameters. The parameters such as cutting speed, feed, and depth of cut were varied in machining the composite with a diamond tool, and the performance was measure in terms of cutting forces and surface roughness. Experimental results however indicated that flood method of machining produced better results than the MQL method, but the MQL method performed nearly equal to the flood method in machining of the composite laminate. This indicates that ultrasonic MQL method is comparable to the flood method and can be improved by changing the machining parameters and optimizing the input parameters.

In another study using oil-based nanoparticles, Molaie et al. used molybdenum disulfide nanoparticles in oil assisted with ultrasonic method in grinding operation [44]. The experimental results clearly indicate that the combined method of ultrasonic grinding clubbed with the conventional MQL method increased the effectiveness of the conventional MQL method and resulted in lower grinding forces. It was also seen from the experimental results that the combined method resulted in lower surface roughness in comparison to the conventionally MQL method which clearly indicates the better lubricity achieved with this hybrid method of fluid delivery.

Madarkar et al. [45] used ultrasonic-assisted MQL method in machining titanium alloy. An indigenous horn was fabricated in order to produce ultrasonic frequency. The authors used sunflower oil with nanoparticles in 1, 5, and 10% concentration and ultrasonic method of fluid delivery. The combined method of fluid delivery performed better than the conventional MQL method as it yielded lower grinding forces than the conventional MQL method. However, the conventional method yielded lower surface roughness than the ultrasonic-assisted grinding process which was due to enhancement in the capacity to retain the sharpness over long period of time than that observed in the conventional MQL method of fluid delivery. Experimental results, however, prove the enhancement in the grindability of titanium alloy with the hybrid method involving ultrasonic and nanoparticles.

Rasidi et al. [46] employed a piezoelectric transducer in micro-machining with MQL method. They compared dry method with MQL method combined with the ultrasonic method in each case and at two different flow rate of the MQL fluid. The experimental results obtained show a slight improvement in the surface finish with the MQL assisted with ultrasonic method. However, the hybrid method improved the tool wear significantly. Similarly, Li et al. [47] reported significant improvement in the tool life of the cutting tool with the ultrasonic-assisted machining with MQL.

Alemayehu et al. [48] evaluated the machining performance in turning Inconel 718 with a new hybrid method. The authors employed ultrasonic vibration with MQL method in machining the alloy. The authors reported that with the unique method of hybrid delivery lower cutting forces were achieved. Thus, this process saves not only input energy but also produces better quality machined surface.

Isobe et al. [49] used carbide drill for drilling with carbide drill vibrating ultrasonically. The authors drilled 302 holes by ultrasonic drilling combined with MQL process. Experimental results showed that the micro-drilling method combined with MQL method was able to reduce the deflections occurring in the drill bit. Not only this, the authors achieved higher tool life with tool wear reducing by almost half.

3 Conclusion

As seen ultrasonic MQL is a relatively newer field and very little literature is published. There is a huge research scope in MQL machining combined with MQL method in machining. It was seen that most of the studies are done in grinding operation only. However, MQL method combined with the ultrasonic machining can be tested in milling and turning operations also. It is recommended to test the effectiveness of MQL in ultrasonic machining on super alloys also.

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