MACROJOURNALS

The Journal of **Macro**Trends in Technology and Innovation

A Technology Enabler in Machining: Nanofluid in Minimum Quantity Lubrication

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Abstract

Nanofluids are a relatively new category of fluids that are created by the dispersal of nanometer-sized particles in base fluids in order to increase tribological properties and heat transfer. Various studies conducted into Nanofluids have shown that the convection heat transfer and the thermal conductivity can be greatly improved by the aforementioned suspended particles. In addition, recent research into tribology shows that the Nano-particle added lubricating fluids have a higher load carrying capacity, friction reduction, and anti-wear capacities. With such features, it is obvious that the Nanofluids are very attractive in lubrication and cooling applications in numerous and various industries. In this paper we review this technology in machining.

Keywords: *Minimum Quantity Lubrication, Nanofluids, Machining*

1. Introduction

Minimum Quantity Lubrication (MQL) is characterized by a massive and drastic reduction in the quantity of lubricant in comparison to the conventional fluid metalworking systems. Minimum Quantity Lubrication has been increasingly adopted in various areas of metal machining and is gradually replacing conventional flooding processing. The main reason behind this adoption is the significant cost savings that result from conducting operations with minimal metalworking fluids use. The potential has been especially recognized by the automotive industry. In the last decades , the automotive industry had experimented and implemented MQL in a number of applications including drilling as reported by Tai et al. (2014).At present the automotive industry is producing numerous components including camshafts, cylinder heads and crankcases among other components that are machined from materials such as steel, aluminum and cast-iron with the aid of highly automated framework using Minimum Quantity Lubrication.as reported by Cable (2013),and Ford Motor Company (2014).

2. Types of Lubricants used in MQL

2.1 Synthetic Esters

These provide the best option in machining processes where a significant lubricating effect to prevent abrasion wear between the tool and workpiece is desired. Examples of such process are; drilling, turning, reaming and threading. Synthetic esters are advantageous in that they have a high boiling and flash points in spite of their low viscosity. The high boiling and flash points translate into much lower emissions of vapor in contrast with conventional emission levels. Furthermore, ester oils are highly biodegradable and are non-hazardous to water due to their low levels of toxicity .Shen (2008).

2.2 Fatty Alcohols

When contrasted with ester oils ,fatty alcohols exhibits a lower flash point with the same viscosity but offer slightly less lubricity. They are mostly preferred for machining processes that have a greater need for separation than they have for lubricating effects. Examples of such a process include the machining of some non-ferrous metals. Fatty alcohols are highly biodegradable, are toxicologically harmless and are not hazardous to water Shen (2008).

it is important to note that some lubricants are unsuitable for minimum quantity lubrication. These include natural oils and greases as a result of their vulnerability to oxidation that gums up the machinery. Lubricants with additives that contain organic zinc or choline. .the resulting high temperatures and pressures can lead to reactions whose products are harmful to health as reported in Deutsche Gesetzliche Unfallversicherung (2010).

3. Minimum quantity lubrication using Nanofluids in machining

Nanofluids are a relatively new category of fluids that are created by the dispersal of nanometer-sized particles in the base fluids in order to increase tribological properties and heat transfer. Various studies conducted into Nanofluids have shown that the convection heat transfer and the thermal conductivity can be greatly improved by the aforementioned suspended particles. In addition, recent research into tribology shows that the Nano-particle added lubricating fluids have a higher load carrying capacity, friction reduction, and anti-wear capacities. With such features, it is obvious that the Nanofluids are very attractive in lubrication and cooling applications in numerous and various industries such as energy, manufacturing, transportation, and electronics among others. The base fluids can include the previously mentioned lubricants (Esters and fatty alcohols) or even water.

3.1 Minimum Quantity Lubrication instrumentation

The primary purpose of minimum quantity lubrication system is to provide lubrication at the tool/workpiece interface at the same time conduct heat away from the cutting zone.
Two modes of delivering the fluid to the cutting zone are used:

a) External feed

The lubrication is applied via spray nozzles located at a distance and surrounding the circumference of the tool.

b) Internal feed

Internal feed devices allow direct supply of the lubrication to the working zone. In these systems, the lubricant is channeled through the tool revolver, or the spindle .The systems allow the lubricant to reach the cutting zone directly which allows for the drilling of deep holes for example more effectively.

There are a number of technologies in use today to store and deliver a lubricant to the cutting zone. These include: Devices with metering pumps, oil droplets target bombardment and devices with pressure tank. The devices with metering pumps transport the lubricant using a pneumatic micro-pump. The dosage of the lubricant is regulated by the frequency and the stroke of the pump plunger. The advantages offered by these devices are the modular design and the exact dosage regulation. Furthermore, the ease of assembly of the pump elements makes the installation of this technology very feasible. Pressure tanks, involve the lubricant to be forced out of a pressurized tank. The metering in these devices is conducted using throttle elements in the pipework and the supply pressure settings. For these devices to be effective, the air atomization tank pressure and the oil quantity should be adjustable separately. The advantages of these devices over the micro pump systems are the lack of moving parts that are subject to wear and the uniform lubrication stream. The oil droplets targeted bombardment shoots single lubricants droplets at the cutting zone trough a high speed valve. The process allows distances of up to 800mm between the tool and the valve without atomization of the lubricant or air mixing. The droplets land on the precise point where they are targeted. The method is used in lubricating very small tools that lack internal cooling systems.

3.2 Nano-fluids in Cooling Applications

Heat transfer fluids are critical in the modern industries such as energy, manufacturing, transportation, and electronics among others. New and emerging developments such as the highly integrated microelectronic devices, reduction in the applied cutting fluids and higher output engines have created a demand for advanced cooling capacities. The result of this has been a critical need to provide innovative techniques to improve the present heat transfer of fluids as reported by Shen (2008).

Heat transfer fluids are limited in the rate of transfer of heat as compared to solids. Therefore, suspending pieces of solids in the liquids results in significant increases in the thermal conductivity of the Nanofluids as compared to conventional heat transfer fluids. The suspension of particles in liquids has been the subject of numerous studies going back a century. However early studies were limited by the technology to millimeter or even micrometer-sized particles that were not small enough to make a significant difference. In the present day, with the development of Nano-particle synthesizing techniques, the proposition to suspend Nano-particles uniformly and in a stable manner in industrial heat transfer fluids are being developed. The aim of this proposition is to generate a new class of engineered fluids that had a high heat transfer rate as reported by Shen (2008). Nano particles are small enough to act as the molecules of the fluids, therefore, do not clog or block the fluid passages but increase the thermal capacities drastically.

3.3 Classifications of Nanofluids

Nanofluids are classified in two categories. The metallic and non-metallic fluids. The metallic Nanofluids contain metallic nanoparticles such as Gold (Au), Iron (Fe), Silver (Ag), and Copper (Cu). The non-metallic Nanofluids contain non-metallic particles such as Silicon Carbide (SiC), Aluminum Oxide (AL2O3) and Copper Oxide (CuO) as reported by Deutsche Gesetzliche Unfallversicherung (2014). The heat conduction models for the solid-liquid mixtures were established more than a century ago with models such as Maxwell model in 1904. The limiting size of these particles however severely limited the heat conduction effectiveness of the fluids .As such when the models are applied to Nanofluids, they tend to underestimate the fluid's thermal conductivity. This latter is best tested by the transient hot-wire method. Metallic nanofluids have been thoroughly and systematically studied, with their respective changes in conductivity being recorded. For example, the thermal conductivity of ethylene glycol improved by 40 percent with the addition of 0.3 percent of Copper nanoparticles of 10 nm in diameter. Also, the thermal conductivity of water has been found to increase by up to 78 percent by adding 7.5 percent Copper particles of 100 nm in diameter as reported by Master Chemical Corporation(2014). Non-metallic fluids such as CuO, TiO2, Al2O3, SiC and even carbon nanotubes have also correspondingly been studied with mixed results. The inconsistencies are attributed to the differences in average particle sizes in the samples used as confirmed reported by Tai et al.(2014).

Carbon nanotubes have been investigated extensively due to their desirable properties . These include extraordinary strength, efficient conduction of heat, and the unique electric properties. Carbon nanotubes (CNTS) are comprised of fullene related structures that are made up of graphite cylinders or a number of concentric cylinders that are concentric. The result of the CNT addition to synthetic oil was simply staggering with an increase of thermal conductivity by 150 percent with an addition of 1 percent particles of carbon nanotubes. This is the highest thermal enhancement ever recorded.Master Chemical Corporation (2014).

3.4 The Process of Manufacture and Production of Nanofluids

There are three primary means of production of the nanofluids,

3.4.1 One-step Physical Process

The process synthesizes the nanoparticles, and disperses them into a fluid in one step as described in Shen(2008). This method was initially used in the preparation of extremely fine particles of Silver through vacuum evaporation of nanoparticles into an oil substrate.

The one-step process of synthesizing nanofluids is very expensive; in addition, the volume of the fluid that can be synthesized by the physical one-step process is limited in comparison to the other production processes.

3.4.2 Two-step Physical Process

In this process, nanoparticles are first fabricated as dry powder through methods such as inert gas condensation. Inert gas condensation involves the vaporization of the nanoparticle source material in a vacuum chamber and the consequent condensation of vapor into nano particles.

The second stage of this process involves the dispersal of the particles into the fluid. This process in hugely advantageous in that it allows the scaling of the technique into an economically viable process producing nanoparticles in tonnage quantities as reported by Shen (2008).

3.4.3 One- Step Chemical Process

The one step chemical process was developed originally to produce stable Copper in ethylene glycol nanofluids through reducing the copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) with another compound; sodium hypophosphite ($NaH_2PO_2 \cdot H_2O$) under microwave irradiation in ethylene glycerol. The improvements to the thermal conductivity are comparable to the improvements of Copper nanofluids prepared in the one-step physical processes. Nevertheless, it is important to note that this method is still in the research stages, and the range nanofluids, that it is capable of synthesizing, are limited Shen(2008).

4. Conclusions

Minimum quantity lubrication has shown to be an effective technology in machining. The benefits include; reduction in costs, saving water usage, saving the lubricants used, increasing the manufacturing plants safety and reducing the adverse effects to the environment, improving machining parts quality, saving on energy consumption, and improving chip recycling .It is particularly advantages when using nanofluids due to their potential high thermal conductivity.

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