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A Review on the Use of Water, Vegetable Oil and Other Liquids as Base-Fluids for Nanocoolants in Machining

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ABSTRACT

Product quality is of utmost important in the manufacturing industry and can be indirectly related to the surface finishing of each product. Meanwhile, surface finishing is affected by high temperature and cutting fluid plays an important role in regulating the development of the heat generated during machining. However, due to some drawbacks of using conventional cutting fluids, nanocoolants are being used in its stead. This paper presents a review on the use of various base fluids such as water, vegetable oil and other liquid as base fluid for nanocoolants in machining processes. The review is based on the effects of these nanocoolants on the improvement to the machining performances through optimized thermal properties. From the review, it can be concluded that the use of nanoparticles in the conventional base fluids such as water, vegetable oil and other fluids may improve the machining performance such as cutting force, tool life and surface finishing but are highly dependent on the following parameters such as temperature, volume fraction and particles size and shape.

Key words : nanocoolant, water, vegetable oil, thermal properties

1. INTRODUCTION

In a many machining processes, heat is generated when the cutting tools needs to overcome the shear strength of the workpiece to perform the cutting action. In principle, heat is the result of plastic deformation in the shear zones and also from the friction that occurs when the tool comes into contact with the workpiece during the cutting process [1]. The heat that results from these actions either flow through the tool, the workpiece or by the chips produced [2]. Though heat is important in order to perform the cutting of the workpiece, it is important to ensure that the heat generated does not affect the quality of the machining process which is often considered from the state of the surface roughness of the final product. One of the ways to ensure this is by using metal working fluids or cutting fluids [3]. The advantages of using cutting fluids are that it helps to lubricate and ultimately cool the interface between the surface of the workpiece and the cutting tools. It also flushes away the debris and chips that are produced during the machining process. These actions result in improved surface finish, increased tool life and allows for the cutting process to be performed at a much reduced amount of time. However, apart from these positive attributes of coolants, as these cutting fluids are sometimes called, there are disadvantages. Apart from incurring extra costs in the manufacturing process itself, the coolants have problems in disposing them as there are possibilities of them causing negative impacts to the environment and to the person handling them. The use of coolants also sometimes may cause thermal shocks to certain cutting materials due to incompatibility. To overcome these drawbacks, nanocoolants are being tested and tried as alternatives to the conventional coolants. Nanofluid is a two phase mixture which is suspension in a nano-size particles in to water or other liquid that can be used as base fluid [4]. Nanofluid has been considered as advanced heat transfer fuid because of their ability to flow smoothly without clogging the system [5]. This review brings together studies that have been conducted on water, mineral oil and vegetable oil based nanocoolants on the effects they have on improving machining performances.

2. REVIEW OF THE USE OF WATER AS BASE FLUID FOR NANOCOOLANT

Water is one of the first and the most common fluid used as coolant which is to regulate or reduce the temperature of a system. An ideal coolant should be of low viscosity, non-toxic and high thermal capacity.

Jarahnejad et al [6] did an investigation on the influence of temperature, concentration and size of nanoparticles on the dynamic viscosity of a nanofluid where the base fluid is water with aluminum oxide (Al_2O_3) and titanium dioxide (TiO_2) as the nanoparticles. They used the capillary and falling ball viscometers to measure the viscosity at different temperatures (between 20 – 50 °C) with a particle concentration of 3-14.3 wt.% They also studied the effect of adding surfactants to the viscosity of the nanofluids. They found that there would be a reduction in the viscosity of the nanofluids at elevated temperatures whereas by adding surfactants the viscosity increased.

Huminic et al [7] investigated the effects of weight concentration and temperature on the thermo-physical properties of fluoroethylene carbonate (FeC)/water nanofluid. The laser pyrolysis technique was used to obtain the FeC nanoparticles and infrared spectroscopy (FI-IR spectroscopy), transmission electron microscope (TEM), energy dispersive x-ray analysis (EDX Raman) and x-ray diffraction (XRD) techniques were used to describe the structure and size as well as to purify the nanoparticles. Three weight concentrations with 0.1, 0.5 and 1.0 wt% in the range of temperature between 10 °C to 70 °C were used to investigate the thermal conductivity, surface tension and viscosity of FeC/water nanofluid. The results showed that the thermal conductivity increased with the increase of both weight concentration of the nanoparticles and temperature while the viscosity became less significant for temperatures above 55°C. Meanwhile, the surface tension of FeC/water increased with the increase of weight concentration of nanoparticles.

Kedzierksi et al [8] measured the liquid thermal conductivities, kinematic viscosities and densities of eleven different synthetic polyolester-based nanoparticle nanolubricants dispersed at temperature between 288 K to 318 K. Zinc oxide (ZnO) and aluminum oxide (Al_2O_3) nanoparticles with nominal diameters of 135 nm and 127 nm, respectively, were investigated. The dispersion of the non-spherical and spherical nanoparticles in the lubricant was maintained using a surfactant. Transient hot wire was used for the thermal conductivity measurement while a Stabinger-type viscometer (Anton-Parr SVM 3000) was used to measure the dynamics viscosity and density. The liquid thermal conductivity, viscosity and density were shown to increase with increasing nanoparticle mass fraction.

Chiam et al [9] conducted a study on the dynamic viscosity and thermal conductivity for different volume ratio mixture of ethylene glycol and water dispersed with aluminum oxide (Al_2O_3). The mixture ratios of ethylene glycol to water tested were 60:40, 50:50, and 40:60. The two-step method was used to prepare the nanofluid mixture. The measurements of viscosity and thermal conductivity were done using Brookfield LVDV-III Rheometer and KD2 Pro Thermal Properties Analyzer respectively. The nanoparticle volume concentration of Al_2O_3 was varied between 0.2 to 1 % under temperature conditions of 30^oC to 70^oC. They found that the thermal conductivity can be enhanced between 2.6% to 12.8% depending on the ethylene glycol concentration. The higher the concentration of ethylene glycol, the greater the enhancement to the thermal conductivity was. The dynamic viscosity was also found to have enhanced up to 5% for the 40:60 ratio and it decreased when the percentage of ethylene glycol was increased. They concluded that temperature, with respect to mixture ratio and concentration significantly influenced the thermal properties of the nanofluids.

3. REVIEW OF USE OF VEGETABLE OIL AS BASE FLUID

The more recent coolant to be used in machining processes is vegetable oil. Vegetable oil is sometimes preferred due to being environmentally friendly and their more preferred physical properties including flash points, high lubricity, biodegradability and renewability [8].

Su et al [10] studied experimentally and theoretically the effect of different ultrasonication times on the dispersion stability, viscosity and thermal conductivity of LB2000 vegetable-based oil and PriEco6000 unsaturated polyol ester dispersed with graphite particles of 35 nm at different concentrations (0.05, 0.25 and 0.5 vol%). The graphite oil-based nanofluids were prepared using the two-step method. They found that the combination of graphite-ProEco6000 nanofluid showed better stability, increased viscosity and thermal conductivity compared to the graphite-LB2000 nanofluid thus making the former better suited for high machining as it can reduce friction as well as higher heat transfer capability.

Sajith et al [11] conducted experiments to study the morphological and composition of aluminum oxide (Al_2O_3) nanoparticles. Viscosities of Al_2O_3 combined with pure coconut oil nanofluids at different solid volume fractions (0.2% to 1.2%) were presented. A rotational Anton Paar rheometer was used to find the shear dynamic viscosity of the nanofluids and to determine the effect of temperature and volume fraction on it. They found that when the amount of nanoparticles in base fluid was increased, the viscosity also increased while when the temperature was increased, the viscosity decreased.

Sadiq et al [12] investigated the lubricating and thermal properties of coconut-oil based silicon carbide (SiC) nanofluid at varying concentrations of 0.35wt%, 0.7wt% and 1.05wt%. KD 2 Pro thermal analyzer was used to measure thermal conductivity while LVDV- III Rheometer was used to measure viscosity of the nanofluid. Results showed that thermal conductivity and viscosity of the nanofluid improved with increase of nanoparticle concentration but decreased with increase in temperature. The enhancement ratio for thermal conductivity was 1.038 while for viscosity at temperatures 30°C and 70°C were 1.277 and 1.397 respectively.

Stief et al [13] conducted experiments to study the effect of solid lubricant assisted minimum quantity cooling lubrication (MQCL) on a tempered ~60 Rockwell Hardness C (HRC) alloyed steel Uddeholm Caldie with cemented carbide tools on the process performance. Nanosized graphite nanoplatelets (GnP) solid lubricant powder was dispersed (0.2% vol.) in rapeseed oil based lubricant via MQCL application. The effect of cutting parameters such as workpiece, chips and tool using dry machining and with MQCL lubrication on the machined surface finish, tool wear, tool forces and vibrations generated were studied. It showed a reduction in heat generation and a decrease of adhesion between tool and workpiece materials. It is well known that the decrease in friction and adhesion interactions in cutting zone influences the chip formation mechanism resulting also in a decrease of the contact length of the tool rake and chips and its variation during machining.

Guo et al [14] conducted a series of grinding experiments to evaluate the lubricating performance of castor oil when mixed with six other vegetable oils (i.e. maize oil, palm oil, soybean oil, rapeseed oil, sunflower oil and peanut oil with a 1:1 ratio. Comparisons were made between the mixtures and with castor oil only. They found that the mixture of castor oil with the other vegetable oils resulted in much better lubricating performance when compared to when castor oil used by itself. The best mixture combination was found to be the mixture of soybean and castor oil. The specific tangential and normal grinding forces were found to have reduced by up to 27.03% and 23.15% respectively with the use of the mixtures. In terms of surface quality, comparisons between four different working fluids of castor oil, castor mixed with soybean oil, castor mixed with maize oil and castor mixed with palm oil showed that the best surface quality came from the use of the soybean-castor oil mixture.

Li et al [15] conducted a research on minimum quantity lubricant cooling (MQLC) of Ni-based alloy grinding using palm oil as the base fluid. Eight different volume fractions of nanofluids (0.5, 1, 1.5, 2, 2.5, 3, 3.5, and 4%) were prepared with carbon nanotube (CNT) nanoparticles. The effect of grinding temperature, grinding capacity and the proportionality coefficient of energies transferred into the workpiece on the viscosity, nanofluid contact angle and thermal conductivity were analyzed. They found that thermal conductivity increased and viscosity of nanofluid improved with the increases of volume fraction. Smaller surface tension will produce smaller nanofluid drops, which more easily enter into the grinding zone and result in better lubrication, thus reducing grinding force, energy input, and grinding temperature.

Padmini et al [16] studied the use of canola, sesame and coconut oils as a base for nanocoolants during the turning process of AISI 1040 steel. The nanocoolants was supplied to the process through the application of the minimum quantity lubrication (MQL) technique. The three different base nanofluids were mixed with the dispersions of nanomolybdenum disulphide (nMoS_2) in canola, sesame and coconut (CC) oils at nano particle inclusions in % (npi) of 0.25%, 0.5%, 0.75% and 1% . Basic properties such as viscosity, density and thermal conductivity was found to have increased with increase in npi. The combination of 0.5% of canola oil and nanomolybdenum disulphide (nMoS_2) was found to exhibit better machining performance compared to all the other conditions. Temperature, toolwear, cutting forces, and surface roughness were found to have reduced by approximately 21%, 44%, 37% and 39% respectively by using CC+nMoS_2 at 0.5% npi compared to dry machining.

Rapeti et al [17] conducted a research to investigated the machining of AISI 1040 steel by using vegetable oil based nano cutting fluids. Nano suspensions of molybdenum di sulphide was dispersed in canola oil, coconut oil and sesame oil to produce the nano cutting fluids. They studied four machining performance indices: cutting temperatures, surface roughness, tool flank wear and cutting force. From their study, they found that when using coconut oil together with 0.5% nano molybdenum di sulphide with a feed rate of 0.14mm/rev and cutting speed of 40 m/min resulted in improved machining performance such as minimum cutting force, cutting temperatures, tool wear and surface roughness. They found that the machining performance was influenced the most by the cutting speed, followed by the feed rate , type of base fluid and level of nanofluids inclusion at 0.25%, 0.5% and 1%.

4. REVIEW OF THE USE OF OTHER LIQUIDS AS BASE FLUID FOR NANOCOOLANT

Compared to water and vegetable oil, there are other types of liquids that are used as base fluids for nanoparticles. This section groups together some of these.

Lee et al [18] through a series of experiments investigated the characteristics of a nanofluid MQL in micro-grinding process. Paraffin oil was chosen as base fluid and nano-diamond and nano-Al_2O_3 particles were selected. A small grinding wheel and a miniaturized desktop machine tool system were used to realize the nanofluid MQL micro grinding process. The results showed that nanofluid MQL was effective for reducing grinding forces and enhancing surface quality. In addition, they listed out the critical parameters that influenced the performance of the nanofluid. They included the size, type and volumetric concentration of the nanoparticles.

Gharaibeh [19] conducted a study examining the impact of different cutting fluids on the surface roughness of aluminium alloy (T6-6061). The test used consistent parameters for cutting which are 860 rpm speed of cutting, cutting depth at 1.5 mm and feed rate of 0.12 mm/rev. Mineral oil, refined sunflower oil (natural used oil) and kerosene were used as the cutting fluid and each of it was mixed with water at different ratios (5%, 10%, 15%, 20%, and 25%) to study their effects on the surface roughness value. It found that the lowest ratio of water is the best result where the lowest roughness obtained. Natural oil and kerosene had the highest roughness coefficients. The study recommended the use of mineral oil as cutting fluids for machines as this could reduce the amount of waste oil from the manufacturing processes.

Su et al [10] studied experimentally and theoretically the effect of different ultrasonication times on the dispersion stability, viscosity and thermal conductivity of LB2000 vegetable-based oil and PriEco6000 unsaturated polyol ester dispersed with graphite particles of 35 nm at different concentrations (0.05, 0.25 and 0.5 vol%). The graphite oil-based nanofluids were prepared using the two-step method. They found that the combination of graphite-ProEco6000 nanofluid showed better stability, increased viscosity and thermal conductivity compared to the graphite-LB2000 nanofluid thus making the former better suited for high machining as it can reduce friction as well as higher heat transfer capability.

5. CONCLUSION

From the review, it can be concluded that the use of nanoparticles in the conventional base fluids such as water, vegetable oil and other liquid may improve machining performances in terms of cutting force, tool life and surface finishing but are highly dependent on the following parameters such as temperature, volume fraction and shape and size of particles.

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