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Experimental Investigation of Recycled Machining Coolant Mixed with Nanofluids Based Al_2O_3

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Abstract. Machining coolant is used in manufacturing industry for lubrication, rusting control and cooling which are crucial in operations such as grinding and cutting process. However, the machining coolant lose efficiency in months due to the thermal degradation and contamination. To recycle the used of machining coolant while enhancing the performance, the mixture of nanofluids (N) based Al_2O_3 with better thermal properties to synthesize with the recycled machining coolant (RMC). This study suspended Al_2O_3 nanofluids in four base ratios of recycled machining coolant (i.e. 0:100, 20:80, 40:60 and 60:40) by ultrasonic homogenies. The three main parameters in cooling rate performance and rusting control are thermal conductivity, dynamic viscosity and pH indication, respectively. The thermal conductivity and dynamic viscosity are then measured at temperature range of 30 to 60 ^oC. The highest enhancement of thermal conductivity was evaluated to be 37.9% higher than machining coolant base fluid at the temperature of 60 ^oC in 60:40 (N:RMC). However, the enhancement of dynamic viscosity was measured to be 4.5% for 60:40 (N:RMC) at 60 ^oC. The pH value of 60:40 (N:RMC) at ambient temperature obtained 8.18 value was nearly neutral and decreased the rusting process. Therefore, this study recommends the use of recycled machining coolants based Al_2O_3 as cutting fluid in the ratio of 60:40 for application in machining operations.

1. Introduction

Machining coolant or lubrication is considered as an accessory in a manufacturing process in order to increase the life of the cutting tool and productivity. The surface quality of the mechanical parts and cutting tools are crucial in evaluating the productivity of a manufacturing industry. In 2018, the amount of machining coolants used in manufacturing industry was reported nearly 38 000 tonnes with an increase of 1.2% compared with the year of 2005 [1]. It is reported that European Union alone is consuming about 320 000 tonnes of machining coolants within one year and two-thirds of it needs to be disposed due to the degradation of thermal efficiency of machining coolants [2]. It is expected that cost of machining coolants, including procurement, preparation, operation and the disposal are approximately 16% of the total manufacturing costs of a product. Therefore, recycling of machining coolant can reduce manufacturing cost and solve waste disposal problems. In 2016, Liang et al. [3] conducted an investigation on the tribological behavior of in-situ exfoliated graphene for water-based lubricants and found that graphene-enhanced lubricants improved the surface quality and coolants durability. Syam Sundar et al. [4] experimentally investigated the thermal conductivity of Al_2O_3 in 20:80 EG/water mixtures compared with 60:40 EG/water base fluids. They found that the thermal conductivity was significantly increased compared to the base fluid with higher ratio of ethylene glycol. The augmentation of thermal conductivity increased the heat transfer coefficient value as stated from Kole and Dey [5]. The average enhancement of heat transfer coefficient was up to 22% in their studied.

Few studies are available regarding to the nanofluids as coolant in machining process. The nanofluid based Al_2O_3 is proposed as a surfactant to synthesize with recycled coolant in order to enhance the performance of machining coolant with better thermal properties. The present study focuses on pH indication, thermal conductivity and dynamic viscosity of Al_2O_3 nano-mixtures in four volume ratios of 0:100, 20:80, 40:60 and 60:40 for measured temperature of 30 to 60 ºC. The optimum volume ratio of nano-mixtures need to be determined by considering the pH value, dynamic viscosity and thermal conductivity as machining coolant for application in machining process.

2. Experimental Procedures

2.1. Preparation of nanofluid and mixture

Nanofluid was prepared by dispersing the nanoparticles in the mixture of water to ethylene glycol fluid. The aluminum oxide, Al_2O_3 nanoparticles in powder form have an average particle diameter of 13 nm size are suspended in nanofluid by using two-step method proposed by Yu et al. [6]. The nanofluid was mixed in four different ratios of recycled machining coolant as base fluids, which were 0:100, 20:80, 40:60 and 60:40 respectively. The ultrasonic homogenizer was employed to improve the dispersion stability of nanoparticles in the mixture. The mixture of Al_2O_3 machining coolant is synthesized by using a magnetic stirrer and sonicated in ultrasonic bath for two hours, followed the studies by Azmi et al. [6-7]. The stability of the nano-mixture is observed and found to be stable for more than two months.

2.2. pH measurement

The pH values were measured by a water-proof hand-held pH meter, Oakton PCTestr-35 by Eutech Instruments Pte. Ltd. The instrument has a combination of pH, electrical conductivity and temperature probes that are user friendly, as illustrated in Figure 1. It can measure pH values between the ranges of 0.00 to 14.00 at a fluid temperatures of 0 to 60 ºC. The instrument was calibrated using the buffer solution provided by the manufacturer. The standard pH buffer solution provided by the manufacturer is at pH values of 1.65, 4.00, 7.00, 10.00 and 12.45. The 5-point pH calibration was done intentionally to ensure accuracy through the pH range [8]. After calibration of the pH meter, the measurement of pH values for Al_2O_3 nano-mixture in different base ratios with 80 ml at ambient temperature were evaluated. The probe as pH sensor was fully immersed into the specimen up to indicator level. The three measurements of each base ratio were collected to generate reliable data, and the average value of the three measurements was taken for analysis. The method of pH measurement was similar to Konakanchi et al. [9] to measure the pH values in their research.

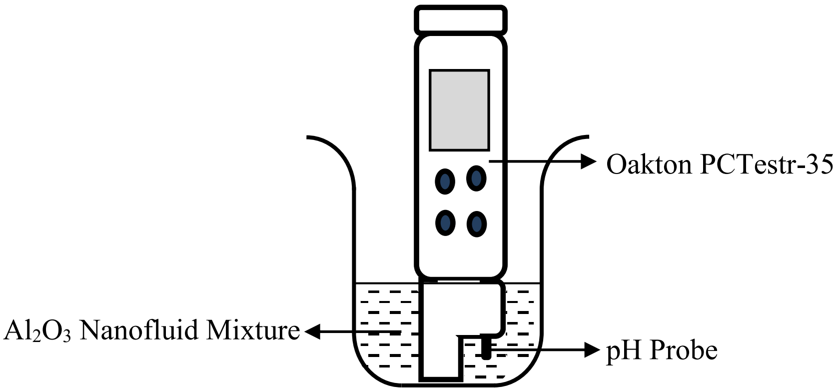

Figure 1. Schematic of pH measurement.

2.3. Thermal conductivity measurement

KD2 Pro thermal property analyzer (Decagon Devices, USA) measured the thermal conductivity of the Al_2O_3 nanofluid mixture, as depicted in Figure 2. The thermal properties of liquids and solids were determined by the device using the transient line heat source. A single needle sensor (KS-1) in the range of 0.002 to 2.00W/m·K was used, and the sensor was validated by measuring the thermal conductivity of the verification liquid such as glycerine that was provided by the supplier. The measured value of glycerine at 25 °C was 0.286 W/m·K, which agreed with the calibrated data of 0.285 W/m·K and within ±0.4% accuracy [6]. The validation process of the sensor was checked before each measurement of thermal conductivity. A water bath of WNB7L1 model by Memmert was used to maintain a constant temperature of the sample with an accuracy of 0.1 °C [10]. Thermal conductivity of four different ratios of Al_2O_3 nano-mixtures were measured within the temperature range of 30 to 60 °C. The consistency of data measurement can be ensured; a minimum of three values were taken for every base ratio at a specific temperature, and the average of the three values was analyzed.

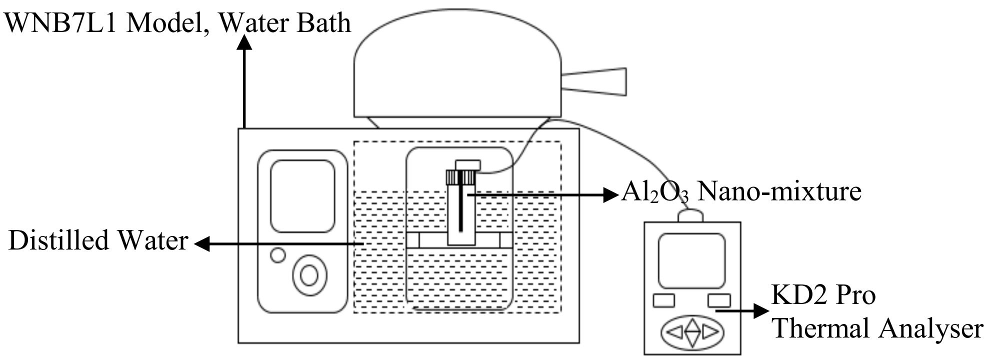

Figure 2. Schematic of thermal conductivity measurement.

2.4. Dynamic viscosity measurement

Dynamic viscosity of Al_2O_3 nanofluid in four different ratios of recycled machining coolant as base fluids were measured by Brookfield (low viscosity digital viscometer) LVDV-III Ultra Programmable Rheometer, as represented in Figure 3. The device is equipped with a RheoCal program in personal computer for data measurement and collection. The viscometer measures the dynamic viscosity of solutions that range from 1 to 6000,000 mPa·s by utilizing an ultra-low adapter. The spindle connected to the viscometer was used to measure nanofluids mixture viscosity [11]. The viscometer drives a spindle that is immersed in nanofluid mixture. Spindle rotation created a viscous drag of the fluid opposite to the spindle, which is measured by the deflection of the calibrated spring. The adapter in this experiment has a provision for temperature circulation of bath fluid. The viscosity of different base ratios of nano-mixtures based Al_2O_3 started from 30 to 60 °C at an interval of 5 °C. Each measurement was conducted three times to generate a reliable data, and the average value of the three values was considered for analysis.

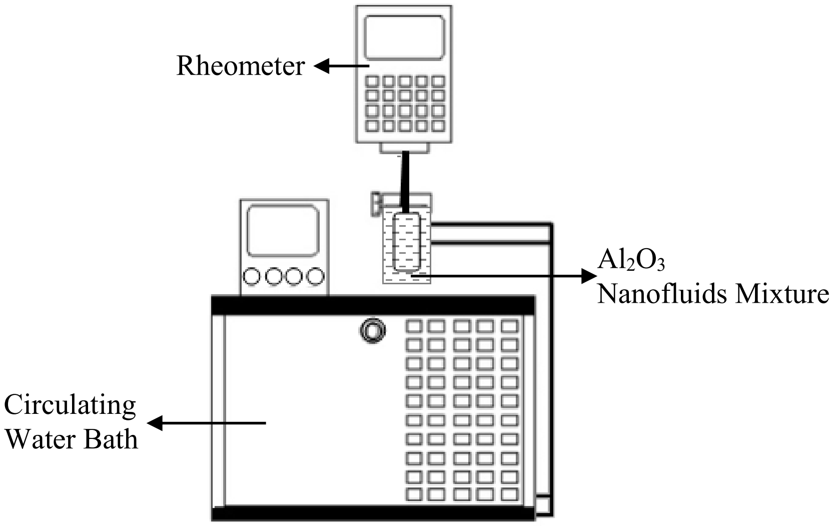

Figure 3. Schematic of dynamic viscosity measurement

3. Results and Discussion

3.1. pH evaluation

According to Scientific, 2015 [12], Al_2O_3 nanoparticles dispersed in mixture of distilled water and ethylene glycol solution have pH measurement in range of 5.0 to 6.5 at ambient temperature condition. However, the nanofluids synthesized with the recycled machining coolants have a pH value of 8.0 to 9.0; and the pH value of machining coolant is between of 8.5 to 9.3 [13]. The percentages of nanofluid based Al_2O_3 applied in this study are 20% to 60% to homogenize with recycled machining coolant as mixture with pH values as shown in Table 1. From the pH indications, it could be seen that the solution chemistry of the nano-mixture is approaching to 8.0, as the percentages of nanofluid increase in the solution. El Baradie, 1996 [14] claimed that pH 7.0 represents neutrality, and the solution with pH value of 8.0 for river water in London readings.

Table 1. pH measurements of several percentages nanofluids mixture

Nanofluids : Recycled Machining Coolant (vol. %)	pH Scale
0 : 100	9.12
20 : 80	8.81
40 : 60	8.57
60 : 40	8.18

3.2. Thermal conductivity of nano-mixtures based Al_2O_3

The thermal conductivity of recycled machining coolant mixed with different ratios of Al_2O_3 nanofluids is shown in Figure 4. As observed from the figure, thermal conductivity is increased with the increasing of temperature and nanofluids percentages, followed the behavior of nanofluid thermal conductivity as stated by Syam Sundar et al. [4] and Lim et al. [6]. However, there is small fluctuation of thermal conductivity occurs at temperature 30 ºC where the percentage of nanofluids 20% higher than 40% nanofluids mixture. In overall, all the nanofluids mixture with the percentage of 60% exhibited the maximum thermal conductivity. The observation seem to be related to the Brownian motion and convection heat transfer of nanoparticles where the increases of nanofluid ratio tends to increase the collision of particles with molecules of base liquid at high temperature [15].

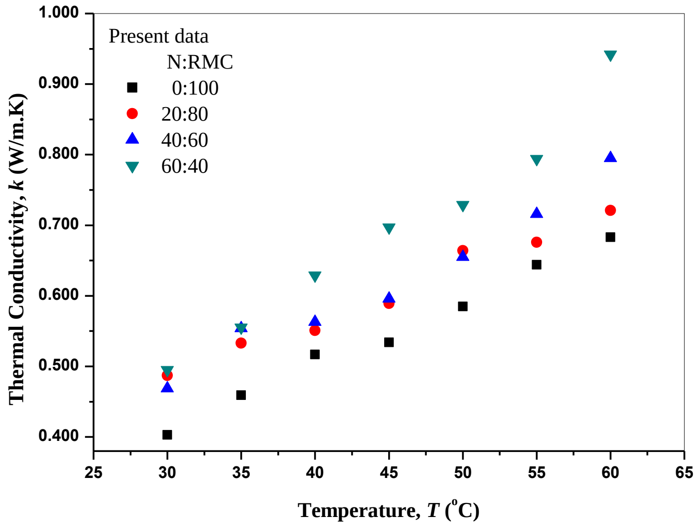

Figure 4. Thermal conductivity of nano-mixtures for different ratios of nanofluid (N) and recycled machining coolant (RMC)

3.3. Dynamic viscosity of nano-mixture based Al_2O_3

The dynamic viscosity measurements of nano-mixtures based Al_2O_3 were conducted in temperature range from 30 to 60 °C as depicted in figure 5. At the base fluids of 60:40 (N:RMC), the dynamic viscosity enhancement percentage was 4.5% at 60 °C compared with that of the 0:100 (N:RMC) base fluids. The dynamic viscosity of the nano-mixture increased as the volume concentration of nanofluid increased. In addition, each volume concentrations have similar increment pattern of viscosity. According to Syam Sundar et al. [16], who found similar pattern of viscosity, it is caused by shear resistance given by the particles onto the fluid. However, the dynamic viscosity of the nanofluid diminished exponentially as the temperature increased. As mentioned by Usri et al. [17] in their research paper, the temperature weakening the inter-particle and inter-molecular adhesion forces.

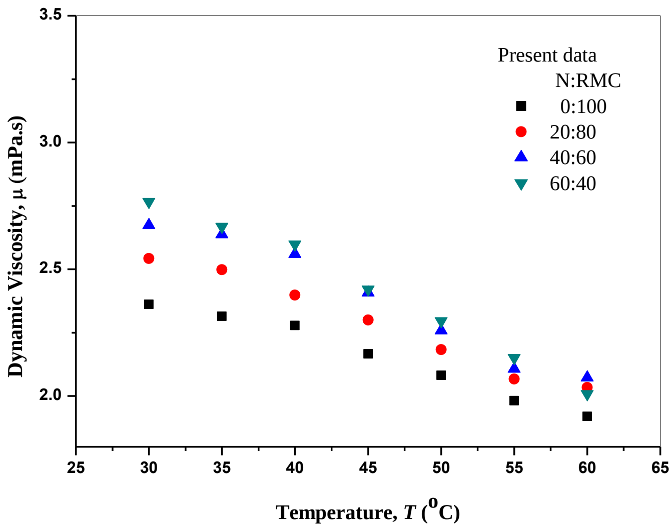

Figure 5. Dynamic viscosity of nano-mixtures for different ratios of nanofluids and recycled machining coolants

4. Conclusion

In this paper, the thermal conductivity, dynamic viscosity and pH indication of Al_2O_3 base nano-recycled machining coolants were investigated. The results showed that pH value of 60:40 (N:RMC) was slightly higher than neutral value of 7.0 and the bacterial growth was prohibited in alkaline condition in order to decrease the rusting process [14]. The experimental analysis found that thermal conductivity increased with the increment of temperature and percentages of nanofluid as base fluids. However, the dynamic viscosity of nano-mixture exponentially decreases with the increase of temperature and the decrease of nanofluid percentages as base fluid.

The thermal conductivity enhancement was determined to be greater than the enhancement of dynamic viscosity. The highest thermal conductivity enhancement increased by 37.9% compared to the machining coolants. However, the enhancement of dynamic viscosity exceed 100% which is not giving benefit to the heat transfer. Therefore, the use of nano-mixtures of 60:40 (N:RMC) based Al_2O_3 is recommended for application as machining coolant to reduce cutting temperatures. Further investigations and experiments on the performance of the machining processes such as milling and turning process by using nano-mixtures as coolants are required to extend the present work.

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