THERMOPHYSICAL PROPERTIES OF QUARRY DUST SUSPENSION AND ALUMINUM OXIDE SUSPENSION AS CUTTING FLUID FOR MACHINING

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ABSTRACT: Particle additive based cutting fluid that have outstanding thermophysical properties play an essential role to reduce the cutting temperature in the machining process. In this study, thermophysical properties, namely thermal conductivity and viscosity of quarry dust suspension and aluminum oxide suspension were investigated experimentally. Both suspensions were prepared by dispersing quarry dust and aluminum oxide particles into the deionized water at various concentrations ranging from 0 wt% until 0.10 wt%. The results indicated that the thermal conductivity and viscosity were improved with the increasing concentration of both quarry dust and aluminum oxide suspension. By using 0.06 wt% of quarry dust suspension, thermal conductivity showed an improvement by 5.39% as compared to aluminum oxide suspension at the same concentration. However, higher viscosity can be obtained by using aluminum oxide suspension. This study provides insights into the thermophysical properties of quarry dust and aluminum oxide suspension, which could be beneficial to the machining industries.

KEYWORDS: *Thermal Conductivity; Viscosity; Quarry Dust; Aluminum Oxide; Cutting Fluid*

1.0 INTRODUCTION

Cutting fluid plays an important role in the machining process. It is primarily used to reduce the friction and cutting temperature between cutting tool and workpiece [1]. Various cooling techniques have been carried out in machining such as cryogenic, dry, flooded and minimal quantity lubrication (MQL)[2-5].

Recently, the use of nanofluid, which is dispersion of nanomaterials into the base fluid, has been widely used in various applications such as electronic device, heat exchangers, and solar energy collectors for the purpose of improving heat transfer [6]. According to Akilu et al. [7], viscosity and thermal conductivity of nanofluids are determined by the particle concentration, base fluid, temperature, particle size, and nanoparticle material. For improvement of the thermal properties, many studies have been conducted employing various nanoparticles in different base fluids. For example, Esfe et al. [6] examined the influence of temperature and solid volume fraction on thermal conductivity of CNTs–Al_2O_3/water nanofluid. The results showed that temperature can significantly improve the thermal conductivity of CNTs–Al_2O_3/water nanofluid, especially at high solid volume fractions. This result is supported by Wei et al. [8], who noted that thermal conductivity of SiC/TiO_2 hybrid nanofluids improved when the volume fractions of nanoparticles and temperature increased. Furthermore, Aberoumand and Jafarimoghaddam [9] discovered that utilising a 1% weight fraction of Cu-engine oil nanofluid can improve thermal conductivity and viscosity by 49% and 37%, respectively. Krishnakumar et al. [10] studied the influence of temperature, particle size, volume fraction, pH and surfactant on thermal and rheological properties of Al_2O_3- ethylene glycol nanofluid. Their results indicated that the nanofluid has a greater thermal conductivity and viscosity than the base fluid, particularly at higher volume fraction. Furthermore, Akilu et al. [7] also reported that SiO_2-CuO/C hybrid nanoparticles improved the thermo-physical properties of the SiO_2 base fluid mixture.

Apparently, various nanoparticles have been studied and reported in the previous researches. However, to the best knowledge of the authors, the study on thermophysical properties of quarry dust suspension is still scarce. Therefore, in this study, the thermal conductivity and viscosity of quarry dust suspension were investigated by using different concentrations. The comparison results with base fluid and aluminum oxide suspension were also reported in the present work. Section 2 explained the methods for the characterization of the particles, preparation of suspension, measurement and analysis. Section 3 discussed the results of thermal conductivity and viscosity of both suspensions. Section 4 concluded the main findings from this study.

2.0 METHODOLOGY

2.1 Characterization of Quarry Dust and Aluminum Oxide Powder

In this study, quarry dust was gained from the Department of Mineral and Geoscience Malaysia (JMG). The particle size range for the quarry dust was 4.936 μm to 147.293 μm, with the average particle size 48.423 μm [11]. The aluminum oxide powder was purchased from Merck. In order to determine the morphology of quarry dust and aluminum oxide, scanning electron microscopy (SEM) (Zeiss EVO 50) was used. X-ray fluorescence spectrometer (XRF) (Siemens SRS 303) and X-ray diffraction (XRD) model PAN analytical XPERT PROMPD were used to determine the quarry dust chemical composition.

2.2 Preparation of Quarry Dust and Aluminum Oxide Suspension

Before the experiment, quarry dust and aluminum oxide suspension with 0.02 wt%, 0.04 wt%, 0.06 wt%, 0.08 wt% and 0.10 wt% were prepared with deionized (DI) water as base fluid. Equation (1) shows the formula for the suspension preparation such as

$$\mathrm{wt\%} = \left(\frac{\text{Weight of Solute}}{\text{Weight of Solution}}\right) \times 100\% \tag{1}$$

where, Weight of Solute (g) = Weight of Powder + Weigh of Surfactant and Weight of Solution (g) = Weight of Base Fluid.

The mixing process was carried out using an ultrasonic homogenizer with a frequency of 24 kHz. Surfactant was dissolved into DI water for 15 minutes at 50% amplitudes and 0.5 cycles. Then, the required amount of powders was dispersed into the mixture for another 50 minutes. To keep the temperature from rising too much during the mixing process, the mixture beaker was placed in a basin filled with cold water. For aluminum oxide suspension, the surfactant used was sodium dodecyl benzene sulfonate, whereas sodium lauryl sulphate was used for the quarry dust suspension.

2.3 Measurement and Analysis

KD2 Pro (Decagon, USA) thermal conductivity analyser was used to determine the thermal conductivity of suspension. During the measurement, the sensor of the KD2-pro type KS-1 was fully immersed in the specimens vertically. Meanwhile, a viscometer type 1C/ E11 from Cannon Instrument Co. was used to measure viscosity.

3.0 RESULTS AND DISCUSSION

3.1 Characterization of Quarry Dust and Aluminum Oxide

Table 1 shows the chemical composition of quarry dust. As can be seen in Table 1, the mass percentage for SiO_2 was the highest (73.5%), followed by Al_2O_3 (11.8%), K_2O (5.46%), Na_2O (3.06%), Fe_2O_3 (2.43%), CaO (1.35%), Rh_2O_3 (0.688%), MgO (0.631%), TiO_2 (0.373%) and others (<0.005%).

Table 1: Chemical composition of quarry dust [11]

Compound	Mass %
SiO_2	73.5
Al_2O_3	11.8
K_2O	5.46
Na_2O	3.06
Fe_2O_3	2.43
CaO	1.35
Rh_2O_3	0.688
MgO	0.631
TiO_2	0.373
Others	<0.005

Figure 1 shows the XRD analysis of chemical compound of quarry dust powder. This result is consistent with the findings of Ramesh et al. [12], where the main compositions of quarry dust were SiO_2 and Al_2O_3. SEM images of quarry dust and aluminum oxide are shown in Figure 2. As illustrated in Figure 2, both of the powders have an uneven shape and size.

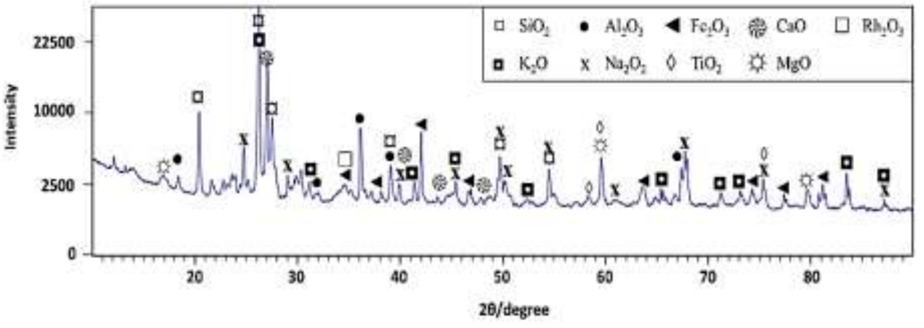
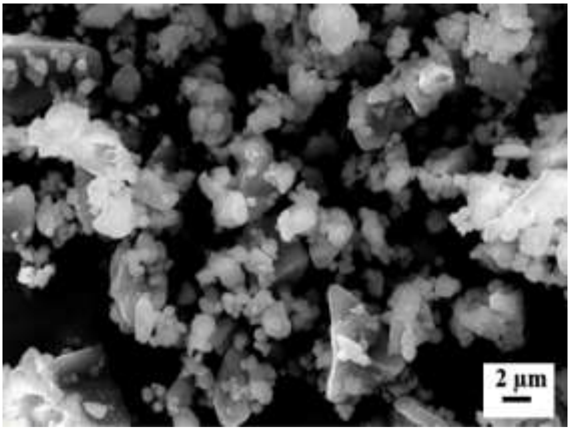
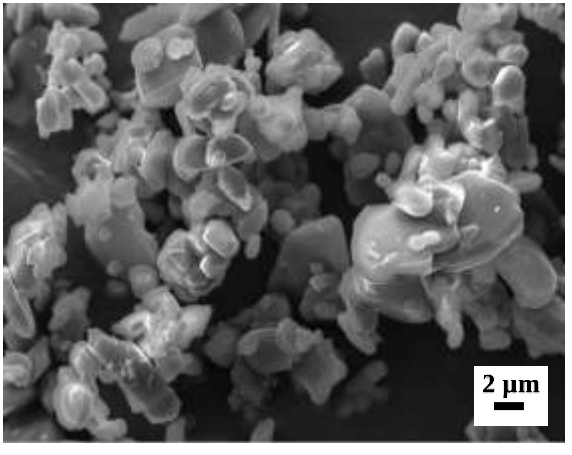


Figure 1: XRD analysis of chemical compound of quarry dust powder



(a)



(b)

Figure 2: SEM images of (a) quarry dust and (b) aluminum oxide

3.2 Thermal Conductivity

Figure 3 shows the effect of suspension concentration on the thermal conductivity. As can be seen in Figure 3, when no powders were added into the deionized water (0 wt%), the thermal conductivity was low. However, the thermal conductivity raised with the increasing of concentrations, and the maximum thermal conductivity was found at the 0.06 wt% for both quarry dust and aluminum oxide suspension. These results are in agreement with that reported by Aberoumand and Jafarimoghaddam [9]. According to their study, the increase in thermal conductivity was caused by the Brownian motion of the particles in the deionized water. However, when both suspension concentrations increased beyond 0.06 wt%, the thermal conductivity tends to decrease. This is consistent with the findings of Wanatasanapan et al. [13], who found that the decrease in thermal conductivity could be attributed to the decline in the dispersion stability.

Furthermore, the thermal conductivity of quarry dust suspension was found to be greater than that of the aluminum oxide suspension. The highest thermal conductivity value of 0.704W/m.K was recorded for the quarry dust suspension at the concentration of 0.06 wt%. Based on the results in Table 1, quarry dust which is composed of several materials like silica (SiO_2), alumina (Al_2O_3) and others, can be considered as hybrid suspension in this case. According to Dalkılıç et al. [14], combining two or more nanoparticles can produce better thermal conductivity results than a single particle. This is due to the close spacing of various nanoparticles size in enriched regions. Moreover, the contact or partial overlap of the liquid layers can also enhance the thermal conductivity [8].

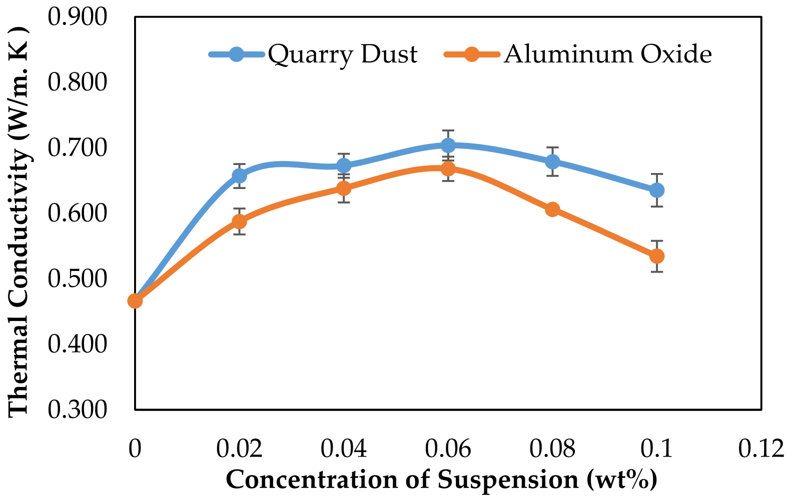


Figure 3: Effect of suspension concentration on thermal conductivity

3.3 Viscosity

The effect of quarry dust and aluminum oxide concentration on the viscosity is shown in Figure 4. It is seen that the viscosity of both suspensions enhanced with the concentrations, although the quarry dust only increased marginally (from 0.008408 cm^2/s to 0.008457 cm^2/s). Similar results were also obtained by Sundar et al. [15]. They claimed that the rise in viscosity at higher volume concentrations was caused by the hydrodynamic interactions between particles, which occurred as the disturbance of the fluid around one particle interacted with other particles. Besides that, it is apparent from Figure 4 that the difference between viscosity of quarry dust suspension and aluminum oxide suspension was extremely little at lower concentration, but it was quite significant at higher concentrations. This finding is consistent with those obtained by Suresh et al. [16].

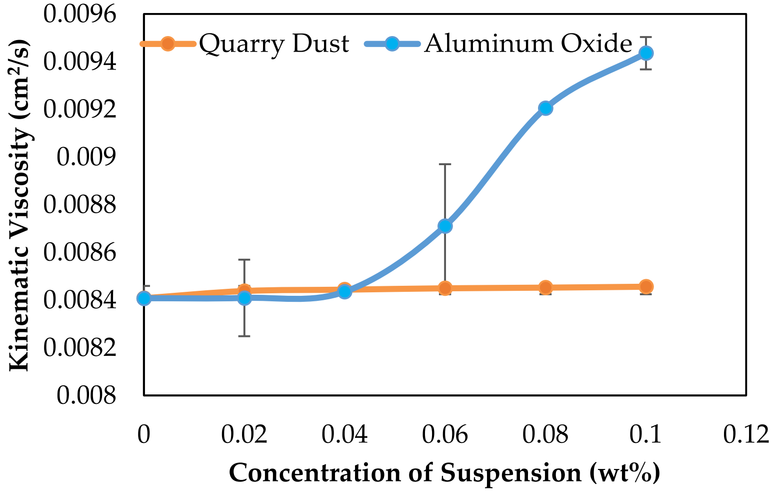


Figure 4: Effect of suspension concentration on kinematic viscosity

4.0 CONCLUSION

In this study, the thermal conductivity and viscosity of quarry dust suspension and aluminum oxide suspension were experimental investigated. Different concentrations of suspension ranging from 0 until 0.1 wt% were prepared by using ultrasonic homogenizer. The significant outcomes of the study are summarized in the points below:

i. The thermal conductivity and viscosity for both suspensions were significantly improved compared to the base fluid (0 wt%).
ii. Thermal conductivity and viscosity of quarry dust and aluminum oxide suspension increased with the increasing of concentration.
iii. Quarry dust suspension produced higher thermal conductivity compared to that of aluminum oxide suspension. However, higher viscosity can be obtained by using aluminum oxide suspension.

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