Thermal and Physical Properties of Graphite Water-based Nanofluids used in Minimum Quantity Lubrication

Yu Su
College of Mechanical Engineering
Jiangsu University of Science and Technology
Zhenjiang, P.R. China
E-mail: suyuliu@sohu.com

Le Gong
College of Mechanical Engineering
Jiangsu University of Science and Technology
Zhenjiang, P.R. China
E-mail: 630653733@qq.com

Dan Dan Chen
College of Mechanical Engineering
Jiangsu University of Science and Technology
Zhenjiang, P.R. China
E-mail: 1264923189@qq.com

Bi Li
College of Mechanical Engineering
Jiangsu University of Science and Technology
Zhenjiang, P.R. China
E-mail: 58863024@qq.com

Abstract—Minimum Quantity Lubrication (MQL) is now being used in some advanced manufacturing processes. Application of MQL reduces the pollution caused by using a large amount of cutting fluid, and makes the working environment become better. However, the conventional lubricants used in MQL result in poor cooling effect. With the rapid development of nanotechnology, researchers begin to explore the nanoscale particles into the liquid, and search for a new and efficient heat transfer cooling medium. In this paper, the two-step method was used to prepare graphite-deionized water nanofluids, and explored the thermal and physical properties of graphite water-based nanofluids. The results suggest that with the concentration increased, the stability of graphite water-based nanofluid decreased. The ultrasonication time had almost no effect on the stability of the prepared nanofluid. The viscosity and thermal conductivity of graphite water-based nanofluid increased with increase in mass fraction of nanographite and ultrasonication time. The surface tension decreased with increase in mass fraction of nanographite and ultrasonication time.

Keywords-Minimum quantity lubrication; nanofluids; viscosity; surface tension; thermal conductivity

I. INTRODUCTION

Nowadays advanced manufacturing industry is moving towards high efficiency and low consumption. However, with the improvement of machining efficiency, the heat in machining zone increases rapidly, which results in the thermal damage of surface of parts, and the reduction in the life and reliability of products. Therefore, the temperature in machining zone must be effectively controlled to reduce the thermal damage on the workpiece surface and to protect tools [1-3]. Minimum Quantity Lubrication (MQL) is a kind of green cooling/lubricating technology, in which a small amount of lubricant is mixed with compressed air to form the mist, and then cools and lubricates the machining zone [4]. MQL enhances the permeability of lubricant during the machining process and its cooling and lubricating effect is significant. Thus, many encouraging results such as the reduction in cutting force and cutting temperature, and improvement of tool life and surface quality, have been achieved in turning, milling, drilling processes [5-7]. But, the conventional lubricants used in MQL have low heat transfer coefficient and small vaporization heat, which limits the cooling effect of MQL. Therefore, it is necessary to search for a new cooling and lubricating medium to further improve the cooling and lubrication capacity of MQL. The concept of nanofluids was first proposed by Choi [8] who worked in Argonne National Laboratory in the United States in 1995. It is a new kind of fluids by dispersing nanometer-sized particles in base fluids. Some research results indicate that the addition of nanoparticles significantly enhanced the heat transfer and lubricating ability of base fluids. With the addition of nanoparticles in base fluids, the internal structure and thermal/physical properties of base fluids change, thus influencing the heat transfer and lubricating ability. In this paper, graphite-deionized water nanofluids with different concentrations were prepared using two-step method, and the effect of ultrasonication time and mass fraction of nanoparticles on the stability, viscosity, surface tension, and thermal conductivity of graphite water-based nanofluid was investigated.

II. EXPERIMENTAL METHOD

The base fluid selected in this research is deionized water, which was purchased from Qianjing Co., Ltd. Due to their excellent thermal conductivity and lubricating performance [9], graphite nanoparticles were used throughout these experiments. They were purchased from Bejing DK Co., Ltd. with the diameters of 35 nm. The graphite-deionized water nanofluids with different mass fractions ranging from 0 to 1 wt.% were prepared by dispersing a certain amount of graphite nanoparticles in deionized water using KQ-100DE ultrasonic cleaner with a 100 W output power and 40 KHZ frequency. The ultrasonication time used was half an hour and one hour for all of the nanofluids prepared.

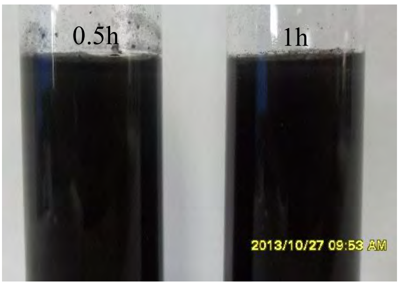
The stability of nanofluids is very important because it plays a major role in the enhacement of heat transfer and friction performance for both scientific and practical applications. Some methods, such as UV-visible optical transmittance method, zeta potential, and sediment photograph capturing, are usually used to rank the stability of prepared nanofluids [10, 11]. In this paper, the stability of graphite water-based nanofluids was examined with photograph capturing method. After synthesis, a small amount of nanofluids were put into test tubes to take photos after certain time until the total precipitation of nanographite. The dynamic viscosity of graphite-deionized water nanofluids for different mass fractions of nanoparticles was measured by a rotating viscometer (model: NDJ-9S). A BZY-1 automatic surface tension meter, which is produced by Shanghai Precision Instrument Co., Ltd., was used for surface tension measurements of nanofluids. The thermal conductivity of nanofluids prepared was measured using TC3010L thermal conductivity measuring instrument (Fig .1), which is produced by Xi'an Xiatech Electronic Technology Co. Ltd., based on the transient hot-wire method. The measurement range of TC3010L is 0.001-5 W/Km. Before measurements, all the instruments were calibrated using pure water or distilled water. All of the measurements were taken three times at room temperature and the average of three values was used for analysis.

Figure 1. TC3010L thermal conductivity measuring instrument.

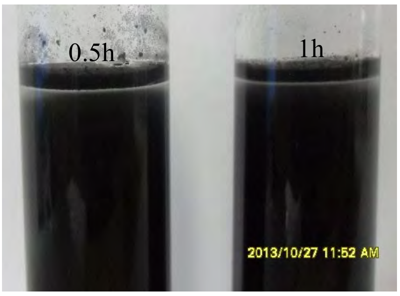
III. Results and Discussion

A. *Effect of concentration of nanoparticles and ultrasonication time on stability*

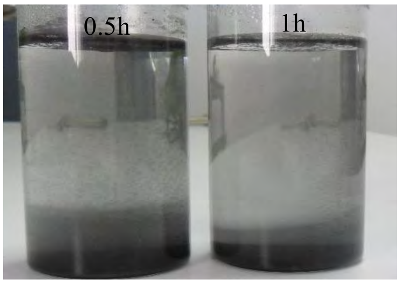
Fig .2 shows the pictures of 0.1 mass concentrations (%) of graphite water-based nanofluids taken on various hours after preparation. It can be seen that sedimentation started after two hours of preparation. And then the graphite-deionized water nanofluids with the mass fraction of 0.1 wt. % became very clear after 96 hours, and nanographite particles almost totally settled to the bottom of test tube. When the concentration of graphite water-based nanofluids increased, the stability decreased. For example, the stability of the prepared nanofluids with the mass fraction of 1 wt. % was only 12 hours (Fig .3). As shown in Figs. 2 and 3, the stability of prepared nanofluids at the ultrasonication time of half an hour was almost the same as that at the ultrasonication time of one hour, indicating that the ultrasonication time influenced the stability very little.



(a) Just after preparation



(b) After 2 hours



(c) After 96 hours

Figure 2. Pictures of graphite water-based nanofluids with the mass fraction of 0.1 wt. % taken on various hours after preparation.

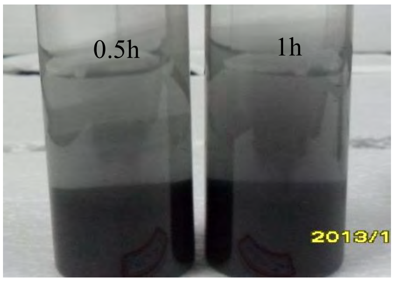


Figure 3. Picture of graphite water-based nanofluids with the mass fraction of 1 wt. % taken on 12 hours after preparation.

B. Effect of concentration of nanoparticles and ultrasonication time on viscosity

Viscosity of nanofluids is one of the most important parameters, which reflects the internal resistance of nanofluids to flow, thus influencing the heat transfer significantly. Fig .4 shows the variation of dynamic viscosity of graphite-deionized water nanofluids as function of nanoparticle concentration at various ultrasonication times. It can be seen that graphite water-based nanofluids showed higher dynamic viscosity than the base fluid. The addition of nanographite with the mass fraction of 0.1 wt. % had a small effect on the viscosity of base fluid. However, when the mass fraction of nanographite reached and exceeded 0.5 wt. %, there was a considerable increase in dynamic viscosity as compared to the base fluid. When the concentration increased, nanographite tended to make an agglomeration within the suspension, which brought about the increase of internal shear stress in nanofluid. Thus, the viscosity of graphite water-based nanofluid increased. In addition, prolonging the ultrasonication time leaded to the increased viscosity of graphite-deionized water nanofluid. This can be attributed to the better dispersion of graphite nanoparticles.

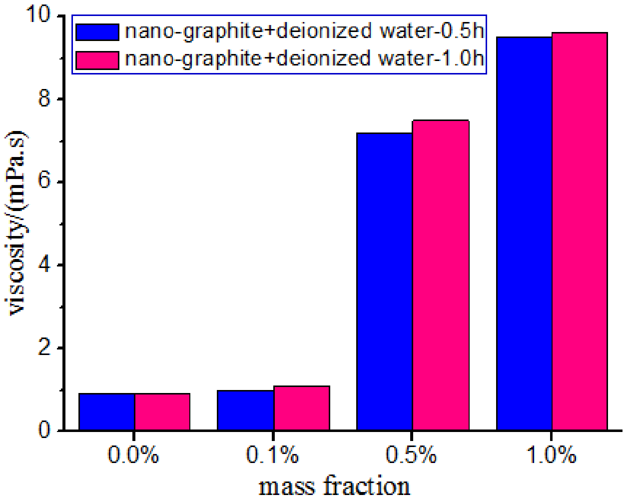


Figure 4. Variation of the viscosity of graphite water-based nanofluids with nanoparticle concentration at various ultrasonication times.

C. Effect of concentration of nanoparticles and ultrasonication time on surface tension

Surface tension is also an important parameter, which has a significant effect on boiling process, wetting behavior, and spray characteristics of nanofluids [12-15]. Fig .5 shows the variation of surface tension of graphite-deionized water nanofluids with nanographite concentration at various ultrasonication times. As shown in Fig .5, the addition of nanographite in base fluid reduced the surface tension of deionized water. And with the increase of mass fraction of nanographite, the surface tension generally declined. The decrease in surface tension was due to the accumulation of nanographite at the surface of deionized water. Besides it, for graphite water-based nanofluid, the surface tension at the ultrasonication time of one hour was lower than that at the ultrasonication time of half an hour.

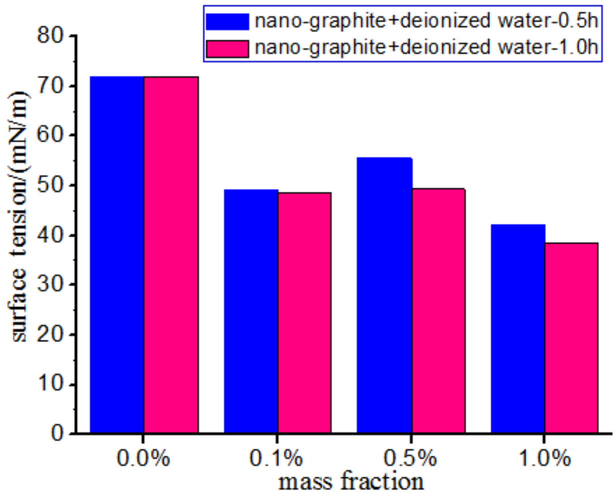


Figure 5. Variation of the surface tension of graphite water-based nanofluids with nanoparticle concentration at various ultrasonication times.

D. Effect of concentration of nanoparticles and ultrasonication time on thermal conductivity

Fig .6 shows the variation of thermal conductivity as function of nanographite concentration at various ultrasonication times. It can be seen that the thermal conductivity of graphite water-based nanofluids increased with increase in mass fraction and ultrasonication time. At the ultrasonication time of half an hour and one hour, the thermal conductivity enhancement for graphite water-based nanofluids was linear and nonlinear with increasing in graphite mass fraction, respectively. The maximum thermal conductivity enhancement was about 4.3% with a 1 nanographite mass fraction and ultrasonication time of one hour. The increase in thermal conductivity was due to the higher thermal conductivity of the added graphite nanoparticles compared to that of the base fluid. Extended ultrasonication time resulted in a more uniform dispersion of graphite nanoparticles, which contributed to the increased enhancement of thermal conductivity.

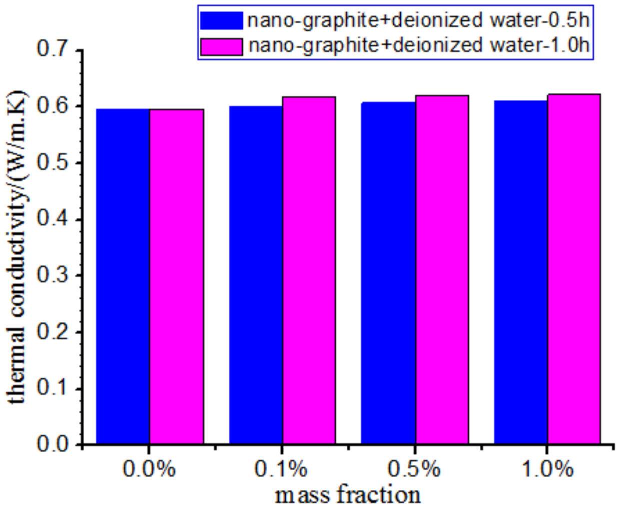


Figure 6. Variation of the thermal conductivity of graphite water-based nanofluids with nanoparticle concentration at various ultrasonication times.

IV. CONCLUSION

The graphite-deionized water nanofluids with different concentrations were prepared using two-step method in this paper. It can be found that the stability of graphite water-based nanofluids decreased when the concentration increased. The extension of ultrasonication time did not improve the stability of nanofluids. The addition of nanographite in base fluid resulted in the reduction of surface tension and the increase of viscosity and thermal conductivity. The viscosity and thermal conductivity of graphite water-based nanofluid increased with increase in mass fraction of nanographite and ultrasonication time. The surface tension decreased with increase in mass fraction of nanographite and ultrasonication time. As graphite-deionized water nanofluid has higher thermal conductivity and viscosity, and lower surface tension than the base fluid, it has better capacity to remove the heat and reduce the friction at the tool-chip interface, thus making it more suitable to be adopted as MQL medium. In the further research work, surfactant addition will be explored to improve the stability of graphite-deionized water nanofluids for long term application.

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REFERENCES

[1] A. Attanasio, M Gelfi, C. Giardini, et al., “Minimal quantity lubrication in turning: effect on tool wear,” Wear, vol.260, pp. 333-338, 2006.

[2] B. Zhao, W.F. Ding, J.B. Dai, et al., “A comparison between conventional speed grinding and super-high speed grinding of (TiCp+TiBw)/Ti-6Al-4V composites using vitrified CBN wheel,” International Journal of Advanced Manufacturing Technology, vol.72, pp. 69-75, 2014.

[3] M. Fahad, P.T. Mativenga and M.A. Sheikh, “An investigation of multilayer coated (TiCN/Al2O3-TiN) tungsten carbide tools in high speed cutting using a hybrid finite element and experimental technique,” Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol.225, pp. 1835-1850, 2011.

[4] K. Weinert , I. Inasaki ,J.W. Sutherland, et al., “Dry machining and minimum quantity lubrication,” Annals of the CIRP, vol. 5, pp.511-538, 2004.

[5] T. Ueda, A. Hosokawa and K. Yamada, “Effect oil mist on tool temperature in cutting,” Journal of Manufacturing Science and Engineering, vol. 128, pp. 130-135, 2006.

[6] I.H. Mulyadi and P.T. Mativenga, “Random or intuitive nozzle position in high-speed milling using minimum quantity lubricant,” Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 228, pp. 21-30, 2014.

[7] E.A. Rahim and H. Sasahara, “Investigation of tool wear and surface integrity on MQL machining of Ti-6AL-4V using biodegradable oil,” Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 225, 1505-1511, 2011.

[8] Choi SUS, “Enhancing Thermal Conductivity of Fluids with Nanoparticle,” ASME F ED, vol. 231, pp.99-105, 1995.

[9] Q.C. Liu, J.T. Xia, S.M. ZHou, et al., “The effect of graphitic crystal defects on lubricity of graphite,” Carbon Techniques, vol. 3, pp.2~4, 2000.

[10] A. Ghadimi, R. Saidur, and H.S.C. Metselaar, “A review of nanofluid stability properties and characterization,” International Journal of Heat and Mass Transfer, vol. 54, pp. 4051-4068, 2011.

[11] Y.J. Li, J.E. Zhou, S. Tung, et al., “A review on development of nanofluid preparation and characterization,” Powder Technology, vol. 196, pp. 89-101.

[12] G. Ramesh and N.K. Prabhu, “Review of thermo-physical properties, wetting and heat transfer characteristics of nanofluids and their applicability in industrial quench heat treatment,” Nanoscale Research Letters, vol. 6, pp.334 -349, 2011.

[13] T. Saad and Q. Li, “Surface tension of Nanofluid-type fuels containing suspended nanomaterials,” Nanoscale Research Letters, vol.7, pp.226-236, 2012.

[14] S.J. Kim, I.C. Bang, J. Buongiorno et al., “Surface wettability change during pool boiling of nanofluids and its effect on critical heat flux,” Int J Heat Mass Tran, vol.50, pp. 4105-4116, 2007.

[15] M.N. Golubovic, H.D.M. Hettiarachchi, W.M. Worek, et al., “Nanofluids and critical heat flux, experimental and analytical study,” Appl Therm Eng, vol. 29, pp. 1281-1288, 2009.