Wear Behavior of Carbon Coated Copper Nanoparticles as an Additive to Bio-based Lubricant

MA Kalam, M. Gulzar, H.H Masjuki, M. Varman, and NWM Zulkifli

Abstract— This study compares the antiwear (AW) characteristics of bio-based lubricant by addition of carbon-coated copper nanoparticles with the case of non-coated copper nanoparticles, determining the effect of carbon coating. For wear elemental analysis in controlled engine environment, a four-cylinder motoring engine test rig was used. The results showed that carbon-coated nanoparticles helped in wear protection of engine parts.

Index Terms—Antiwear, bio-based, nanoparticles, dispersion

I. Introduction

For the formulation of nanolubricants, in addition to chalcogenides and metal oxides, metallic additives have also been investigated [1, 2]. The advantages of using metallic nanoparticles include high load carrying capacity, corrosion resistance and effectiveness at high temperatures [3]. Therefore, such nanoparticles have the potential to provide suitable wear protection and high load carrying ability. Among the metallic nanoparticles, a number of previous research have reported the wear protection and friction behavior of nanolubricants dispersed with copper nanoparticles [2, 4-8].

In all these studies uncoated copper nanoparticles were used. With the recent advances of carbon coatings for improved tribo-pair interaction, few of the studies have used carbon coated copper nanoparticles [1] [3] and better wear protection and improved friction reduction has been reported than that of uncoated copper nanoparticles. This improved tribological behavior for carbon coated nanoparticles has been observed when carbon coated nano copper were dispersed in synthetic lubricants.

To the best of our knowledge, no technical studies have explored carbon coated copper nanoparticles as additives for bio-based lubricant. To address this gap, the present study investigates the AW characteristics of chemically modified palm oil (CMPO) enriched with uncoated nanoCu as well as carbon coated nanoCu.

Manuscript received October 6, 2016. This work was supported in part by the University of Malaya.

Authors Affiliation: Centre for Energy Sciences, Department of Mechanical Engineering, University of Malaya, Kuala Lumpur, Malaysia.

II. Materials and Methods

A. Nanolubricants Formulation

Commercially available nanoparticles were used in this study for which the true size and density was provided by the supplier. Fig. 1 shows the morphology of used nanoparticles. Table 1 shows the material properties of both type of nanoparticles. For uniform dispersion of nanocomposites in CMPO, ultrasonic probe was used at 30 ^{0}C. Initially four different nanoCu wt% concentrations i.e. 0.50%, 0.75%, 1% and 2 % were dispersed in CMPO but low wear protection and load carrying ability was observed at 0.5 wt% and 0.75 wt % for both type of nanoparticles. Therefore, copper nanoparticles concentration of 1 % and 2 wt% were adopted and presented in this study. Five lubricants will be tested which will be stated as Oil A, Oil B, Oil C, Oil D and Oil E in this paper.

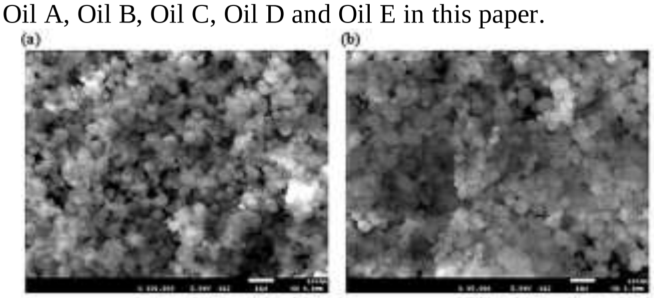

Fig. 1 SEM micrograph (a) Copper nanoparticles (b) Carbon coated copper nanoparticles

TABLE I
Material properties for used nanoparticles

Material	Purity (%)	Color	Morphology	Average particle Size (nm)	Melting Point ^{0}C
Copper (Cu)	99.8	Black brown	Nearly spherical	25	1083
Carbon Coated Copper (CuC)	99.8	Black	Nearly spherical	25	1083

B. Dispersion Analysis

Dispersion stability of all nanolubricant samples was experimentally observed by observing the optical absorbance spectrum. For this purpose, a SPEKOL 1500 UV VIS spectrophotometer was used and tests were conducted at a wavelength of 429 nm with a repeatability of 1 nm. CMPO as well as nanolubricant samples were placed in glass cuvettes of 3.5ml capacity while CMPO was used as a reference solution. The time rate changes in the absorbance level of visible light was noted to measure the samples dispersion ability.

C. Engine Testing

To evaluate the lubrication performance of considered lubricants while duplicating the engine conditions in a controlled environment, a 100 kW, four cylinder motored test rig was used. The motoring engine test rig was instrumented with oil, coolant temperatures and air flow rate. The special functions involve the dedicated sampling system from oil sumps for wear metal analysis. The overall system allows different lubricants and additives to be optimized by controlling the engine speed, lubricant and coolant temperatures. For all the lubricants the engine was operated for ten hours for each lubricant sample at 2000 rpm with average lubricant temperature of 100 ^{0}C. The schematics of motoring engine test rig is given in Fig. 2. As measuring the concentration of wear metals accumulating in used engine oil is an accepted method for monitoring engine wear, a multi-element oil analyzer (MOA) was used to measure wear metals (Fe, Cr, Al, and Pb) in sump oil samples after each test.

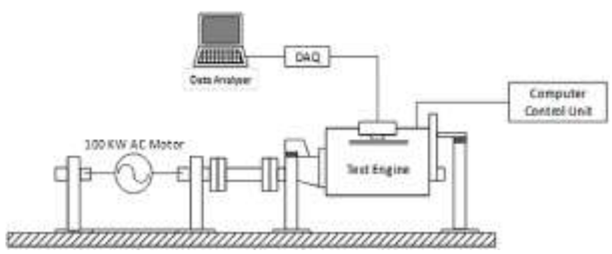

Fig. 2 Schematics of 100 Kw motoring engine test rig.

III. RESULTS AND DISCUSSION

A. Dispersion Stability

Fig. 3 shows the dispersion stability of nanolubricants in terms of optical absorbance. For the case of uncoated Cu, the optical absorbance profiles show that the increasing concentration of nanoparticles from 1% to 2 %, decreases the optical absorbance ability of nanolubricant samples. For higher concentration i.e. 2 wt % of uncoated nanoCu, the tendency of agglomeration was observed and higher sediments were present at the end of test. On the other hand, stable dispersions were observed for carbon coated Cu with low rate of agglomerates and lesser sediments than that of uncoated samples. This trend shows that carbon coated copper nanoparticles have more tendency to suspend in CMPO as compared to uncoated copper nanoparticles. Among the considered cases, most stable dispersion has been seen for nanolubricant with 1 wt % carbon coated copper nanoparticles.

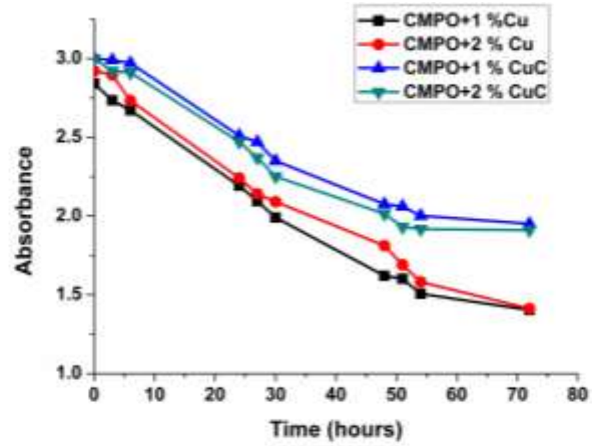

Fig. 3. Dispersion stability of nanolubricant samples in terms of optical absorbance.

B. Wear elemental analysis

The wear metals debris tend to remain dispersed in the engine oil as they are not captured by the oil filter, therefore, sump oil samples were analyzed for wear metals concentrations. As the copper nanoparticles in all suspensions have the ability to pass through the oil filter, the presence of high copper concentrations in sump oil samples were not indication of actual engine parts wear. Therefore, to characterize the engine wear iron, chromium, aluminum and lead concentrations were compared for all nanolubricant samples. Wear elements concentration details of each nanolubricant samples is shown in Fig. 4. In all the considered lubricant samples, iron (Fe) was found to be the most abundant wear metal. The sources of iron in wear debris is believed to be result of wear of cylinder liner, piston rings, valves, gears, shafts, bearing, rust, and crankshaft. The lowest iron metal concentration was observed for Oil D which was enriched with 1 wt% carbon coated nanoCopper. Chromium (Cr) is most often found in the piston rings [9]. Very low concentrations of Cr were resulted by using all the trial oils. The overall wear protection trend was similar as Oil D provided the lowest concentrations of Cr. Aluminum (Al) particles come from piston, bearings, push rods, oil pump and gears [10]. For Al, the wear trend shows that Oil D provides the lowest wear loss. Similarly, less wear metal particles of lead (Pb) were reported for all the nanolubricants which shows their low corrosion ability as the Pb concentrations in oil samples is due to corrosion on bearing surfaces [9].

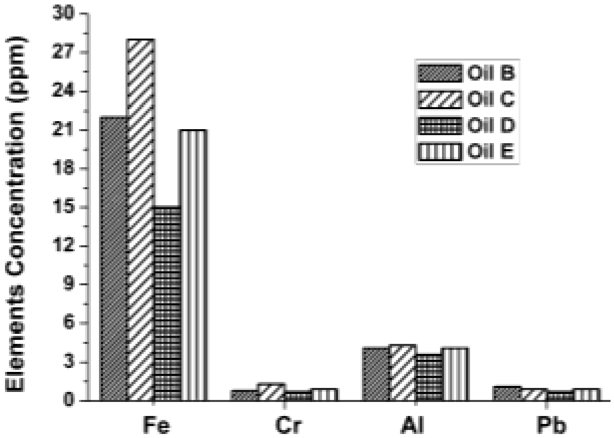

Fig. 4. Wear metals analysis of nanolubricants.

IV. Conclusion

As a result of this research, the following conclusions can be drawn:

1. Carbon coated nanoparticles improved the dispersion ability hence uniform surface mending and improved load carrying ability has been observed for suspension containing carbon coated nanoparticles. 1 wt % carbon coated nanoparticles provided the most stable suspension with CMPO.
2. Motored engine test rig shows that 1 wt% carbon coated nanoCu provided most suitable wear protection.

Acknowledgment

The authors would like to thank the University of Malaya, which made this study possible through the High Impact Research Chancellory Grant, Project title: ‘‘Development of Alternative and Renewable Energy Carrier’’ Grant Number: UM.C/HIR/MOHE/ENG/60 and UMRG Grant CG 060-2013.

References

[1] Y. Xu, H. L. Yu, B. S. Xu, X. L. Wang, and Q. Liu, "Preparation and tribological properties of surface-coated nano-copper additives," in Key Engineering Materials, 2008, pp. 580-584. https://doi.org/10.4028/www.scientific.net/KEM.373-374.580

[2] H. L. Yu, Y. Xu, P. J. Shi, B. S. Xu, X. L. Wang, Q. Liu, et al., "Characterization and nano-mechanical properties of tribofilms using Cu nanoparticles as additives," Surface and Coatings Technology, vol. 203, pp. 28-34, 10/25/ 2008.

[3] J. L. Viesca, A. Hernández Battez, R. González, R. Chou, and J. J. Cabello, "Antiwear properties of carbon-coated copper nanoparticles used as an additive to a polyalphaolefin," Tribology International, vol. 44, pp. 829-833, 7// 2011.

[4] Y. Choi, C. Lee, Y. Hwang, M. Park, J. Lee, C. Choi, et al., "Tribological behavior of copper nanoparticles as additives in oil," Current Applied Physics, vol. 9, pp. e124-e127, 2009. https://doi.org/10.1016/j.cap.2008.12.050

[5] J. Padgurskas, R. Rukuiza, I. Prosyčevas, and R. Kreivaitis, "Tribological properties of lubricant additives of Fe, Cu and Co nanoparticles," Tribology International, vol. 60, pp. 224-232, 4// 2013.

[6] H.-l. Yu, Y. Xu, P.-j. Shi, B.-s. Xu, X.-l. Wang, and Q. Liu, "Tribological properties and lubricating mechanisms of Cu nanoparticles in lubricant," Transactions of Nonferrous Metals Society of China, vol. 18, pp. 636-641, 6// 2008.

[7] J. Zhou, Z. Wu, Z. Zhang, W. Liu, and Q. Xue, "Tribological behavior and lubricating mechanism of Cu nanoparticles in oil," Tribology Letters, vol. 8, pp. 213-218, 2000. https://doi.org/10.1023/A:1019151721801

[8] Y. Zhang, Y. Xu, Y. Yang, S. Zhang, P. Zhang, and Z. Zhang, "Synthesis and tribological properties of oil-soluble copper nanoparticles as environmentally friendly lubricating oil additives," Industrial Lubrication and Tribology, vol. 67, pp. 227-232, 2015. https://doi.org/10.1108/ILT-10-2012-0098

[9] S. A. G. Watson, "Lubricant-derived ash: in-engine sources and opportunities for reduction," PhD, Massachusetts Institute of Technology, 2010.

[10] S. K. Singh, A. K. Agarwal, and M. Sharma, "Experimental investigations of heavy metal addition in lubricating oil and soot deposition in an EGR operated engine," Applied Thermal Engineering, vol. 26, pp. 259-266, 2// 2006.

Dr. Md. Abul Kalam is working as an Associate Professor in the Department of Mechanical Engineering, University of Malaya since Sept 2015 to date. His research specialization is on Internal-combustion engine, Biodiesel/Biofuel, Lubricant testing and Engine Tribology.
Dr. Kalam obtained his undergraduate degree from Bangladesh Institute of Technology (B.I.T) Khulna, Bangladesh, (Presently known as KUET, Bangladesh), and Master & Ph.D. from University of Malaya (Malaysia).