Influence of Adding CuO and MoS$_2$ Nano-particles to Castor Oil and Moulding Oil on Tribological Properties

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Abstract. The tribological properties of adding copper oxide (CuO) and molybdenum disulfide (MoS$_2$) nanoparticles powder in both organic (castor oil) and mineral oil (moulding oil) were investigated. These properties include coefficient of friction and wear between two surfaces, CK50 steel alloy and 2024-T4 aluminum alloy. The Nano lubricants were prepared by dispersing CuO and MoS$_2$ nanoparticle powders at variable weight fractions 0.3, 0.5, 0.7, 1.0 and 2.0% in each oil lubricant. The friction and wear tests were carried out using a pin on the disk test principle by the vertical universal friction testing machine (MMW-1A). The instability problem with the lubricant suspension was solved by adding different weight fractions of GUM ARABIC, which leads to 2% of it gives more stable suspensions. The best results from both friction and wear Tribological tests are observed in 1%W of adding both nanoparticles to both oil lubricants. The formation of Tribo film due to the adsorption and adherence of Nano additives on the surfaces was responsible in reducing the wear properties. Hybrid (1%Wt CuO + 1Wt% MoS$_2$) nanoparticles that added to both oils indicates more decreasing in friction and wear compared to the base oil. The coefficient of friction for hybrid Nano-particulate lubricants reduced to 81.7% and 76.03%, while the wear rate reduced to 93.17% and 92.23% compared to castor oil and moulding oil respectively as a base oil. The study provides insights into how Nano-lubricant additives could contribute towards tribological enhancement and improved product quality.

Keywords: Coefficient of friction, Wear rate, Nano-particulate lubricant, Tribology, Gum Arabic

1. Introduction:
Lubrication is one of the most used solutions to overcome friction problems. For many years, various liquid oils and greases have been used as lubricants to make one surface slide smoothly over another, such as bearings or pistons in their chambers or wheels on their axes [1].

Lubricant performs a number of critical functions; it includes lubrication, reduction in friction and wear, cooling and protecting metal surfaces against corrosive damage [2]. Most of the lubricants that are produced from mineral oil don't have all the desired tribological properties. It has already been established that the addition of solid particles to oils improve the tribological properties of lubricants to a large extent [3].

Nano particles take a revolutionary role in modern life. It has at least one dimension less than 100 NM so based on their unique size-dependent properties; these materials are superior and indispensable in many areas of human activity [4]. The addition of nanoparticle to lubricants decreases friction and wear due to the presence of rolling friction instead of sliding friction. Nano lubricants have raised
great interest in Tribology management, due to their excellent control over excessive heat and friction between the moving parts of an engine [5]. Nano fluid lubricants demonstrate superior thermal and mechanical characteristics compared with the traditional bare lubricating oils. Nano effect on the surface has been proven as an improvement to the surface finish in a thin layer of Al₂O₃. Nano particles of steel can be obtained by various means (N. Sudheerkumar et al., 2015). This layer works as surface protection to the metal [1- 6]. Hence, for enhancing certain characteristics, such as friction and wear resistance; Sheida Shahnaz et al., 2016 proved that Nano powders are used with oil lubricated a hybrid. But, there are also some challenges hardwired to their applications. The most important challenge, is to prepare and maintain homogenous mixtures of nanostructure particles and oils [6].

C.J. Tana et al. (2016) investigated the effects of suspending with different Nano particle concentrations on the increasing ironing limit of Al alloy cylindrical cups in deep drawing process. The limit was 10.4% higher than the one obtained with base oil [7]. Deep drawing is classified as one of the most important and common sheets forming process. This method is very qualified to produce large amount of simple shape parts like cups, cans, vessels, etc. [8].

Increasing the concentration of nanoparticle additives has contributed to friction reduction. It also affects the performance of deep drawing process by evaluation of forming load, friction coefficient and surface quality [9].

The CuO Nano powder was selected according to its ability of forming a third body layer [10]. Due to mechanical compaction and extreme pressure related to the size and the hardness of nanoparticles when add to a lubricant which give a Friction and wear reduction, anti-contact fatigue, good extreme pressure [11]. MoS₂ Rolling/sliding at the low normal stress and exfoliation at the high normal stress under boundary lubrication and Layers in the particles can easily slide due to weak intermolecular interactions [12]. These properties qualify it as a good additive to lubricants. Its favorite for the efficient delivery of particles to the asperity contact which helps reducing sliding friction, by up to 50% in the mixed lubrication regime [13].

This work, studied the tribological properties for the influence of adding CuO and MoS₂ nanoparticles to each castor oil and moulding oil, and as a hybrid of both nanoparticles at 1% Wt to each oils. Pin on disk method was used according to ASTM G99 standard. This paper now studies the stability of the suspension and the anti-wear and anti-friction behaviour of the CuO and MoS₂ nanoparticle suspensions in two different oils (moulding oil and castor oil) under mixed lubrication with different concentrations.

2. Experimental details/procedure:

2.1 Additives:
The information on used additives is listed in Table (1)

| Supplier Information | CuO                      | MoS₂                      |
|----------------------|--------------------------|---------------------------|
| Company              | ZHENGZHOU DONGYAO        | AESAR, A BRANCH OF JOHNSON MATHEY INC. |
|                      | NANO MATERIALS CO., LTD  |                           |
| Place of origin      | Henan. china (Mainland)  | Seabrook, NH, USA         |
| Grade Standard       | Electron Grade. Industrial Grade | Industrial Grade          |
| Purity (%)           | 99.9                     | 99.9                      |
| Average Particle size (nm) | 55                       | 60                       |

The scan electron microscope technique is used to configure the particle shape and the average particle size. SEM images inspected by NANO SPECIALIST CENTER / MATERIAL RESEARCHES DEPARTMENT / MINISTRY OF SCIENCE AND TECHNOLOGY in figure 1 consist of nearly
spherical shape of CuO and irregular layer shape for MoS$_2$. Also, they indicate that the average particle size is approximately 30nm.

![SEM Image with 50.0 kX magnification power for particulate additives.](image)

(a) CuO  
(b) MoS$_2$

**Figure 1.** SEM Image with 50.0 kX magnification power for particulate additives.

### 2.2 Nano Lubricants preparation:
Nano lubricant is a Nano powder with the base fluid as a conventional lubricant [14]. The Nano lubricants were prepared by using moulding oil and castor oil as the base fluid. Oils properties are tabulated in Table 2. Two step preparation techniques were used for the preparation of the Nano lubricant [15]. The process was started with the dispersion of Nano powders in different weight fractions (0.3, 0.5, 0.7, 1.0 and 2.0 for both powders) using the magnetic stirrer for 15 min. Then, using the ultrasound probe for 15 min. Ultrasound is a newborn technology envisaged to have a potential impact on turbulent energy dissipation rates [16].

**Table 2.** The properties of based oils.

| Lab. Insp. Data         | Moulding oil | Castor oil |
|-------------------------|--------------|------------|
| Vis. C.st. @40 °C       | 15.37        | 250.41     |
| Vis. C.st. @100 °C      | 03.61        | 19.28      |
| V.I                     | 119.00       | 86.00      |
| SP. Gravity at 15.6 °C  | 0.8579       | 0.9624     |
| COC flash point °C      | 190.00       | 306.00     |
| Pour point °C           | −9.00        | −18.00     |

### 2.3 Lubricants Stability:
Due to the Van der Waals force and other forces existing between the Nano particles, the solution of Nano additive most likely tends to agglomerate and settle apart from the oil [17]. To overcome this problem, a natural ingredient was used to call GUM ARABIC as a surfactant. Surfactants act as a spacer between nanoparticles, avoiding agglomeration of nanoparticles and thereby maintaining the stability of the suspension [18].

GUM ARABIC was used and tested in different percentages (1%, 1.5% and 2%) (All percentages were tested with 2% Nano additive). It was dispersed in oil using a magnetic stirrer for 15min. before mixing the Nano powders with the suspension.
Tests were carried out using a zeta potential device which is a key indicator of the stability of colloidal dispersions. The magnitude of the zeta potential indicates the degree of electrostatic repulsion between adjacent, similarly charged particles in dispersion [19]. Results show that with increasing the percentages of GA, the stability, increased gradually up to the good stability state. By increasing the
zeta potential values, the tendency to agglomeration decreases which leads to a more stable suspension [20].

2.4 Sample Preparation:
Samples were prepared according to pin on disk test principle. The pin metal is 2024 T4 aluminum alloy and the disk CK 50 steel. The shape and dimensions of pin were (6×16) mm cylinder. The ring was (16, 32 and 11) mm in inner diameter, outer diameter and height, respectively.

2.5 Friction and Wear:
Vertical universal friction testing machine (MMW-1A) used for friction test, according to ASTM G99 standards. Experiments were conducted at room temperature. The tests performed at a constant sliding velocity of (1.5176 m/s) and different loading conditions (100, 140, 180, 220 and 260) N. Test duration was fixed at 10 minutes for each experiment. All experiments results were average of three pins in order to reproduce the results. Results of friction and wear test show a significant enhancement in COF and wear. Cases compared were dry state compared to wet using moulding and castor oil. Then, with the addition of the CuO and MoS$_2$ to each of oils separately and last is the hybrid of both Nano powders. Wear results were calculated by weight loss, according to ASTM G99 standard from the equation [21].

\[
WR = \frac{\Delta w}{SD}
\]

Where: WR: Wear rate (gm/cm),
\(\Delta w\): Weight difference of sample before and after each test (gm), and
SD: Total sliding distance (cm).

3. Results and Discussion:

3.1 The Stability of Lubricants
Mixing MoS$_2$ of 2%W with moulding oil has zeta potential value of 24.20- mV. According to ASTM standard D4187-82, 1985; for the stability of suspensions with relation to zeta potential, it tends to agglomerate and precipitation with a mobility of 1.89- (μ/s)/(V/cm) as shown in figure 2.

![Figure 2. Curves of zeta potential value and mobility for MoS$_2$ additive in moulding oil without the addition of GA.](image)

The stability of the mixture is increased to 30.49 mV after adding 1%Wt of GA, also increasing to moderate stability with mobility of 2.38-(μ/s)/(V/cm) as shown in Figure 3. It gives 50% enhancement to suspension.
Figure 3. Zeta potential and mobility for MoS\(_2\) in moulding oil with the addition of 1\% Wt GA.

After the improvement of GA addition, the test went to a more challengeable level. Now testing CuO zeta potential with increasing GA percentage up to 1.5 Wt\%. Since CuO has a heavier molecular weight and tends to deposit [22]. Figure 4 illustrates the results of zeta potential value is 38.83- mV and mobility of 3.03- (\(\mu/s\))/(V/cm).

Figure 4. Zeta potential and mobility for CuO in moulding oil with the addition of 1.5\% Wt GA.

Comparing the stability of previous tests with castor oil at same weight fraction, results shown an excellent stability level with a zeta of -160.78 mV and mobility of 3.19- (\(\mu/s\))/(V/cm) as shown in figure 5.

Figure 5. Zeta potential curve and mobility of CuO in castor oil with 1.5 Wt\% GA.

Now for a better enhancement to CuO-moulding oil suspension, the weight fraction of GA was increased to 2\% Wt. It showed an improvement to the good stability level at 45.39- mV zeta potential and a mobility of 3.55- (\(\mu/s\))/(V/cm) as shown in figure 6.

The stability of suspensions appears to the observant. It was obvious that the oil containing GA with the highest percentage was the darkest as appear in figure 7.
3.2 Coefficient of Friction COF:

Nano particle concentrations improved COF values significantly. However, results for each suspension differed depending on nanoparticle concentration. The lowest friction coefficient was at concentration of 1\% Wt of each powder. CuO showed a higher COF than MoS\textsubscript{2}. Castor oil generally had a better result compared to moulding oil. Since, The 1\% Wt of two powders had the lowest COF and exhibited the best tribological behavior, a hybrid particulate lubricant consisting of 1\% CuO + 1\% MoS\textsubscript{2} 2\% GA was prepared for both types of oils showing the lowest COF of all results.

The comparison between all particulate lubricants base castor oil and moulding oil with COF values are illustrated in Figure 8. The enhancement of using castor oil and moulding oil as a lubricant over the dry condition is approximately 51.96\% and 55.25\% respectively. Generally, COF decreases with the Nano addition are in the range of 50\% to 82\%. This decreasing tendency is due to the ability of Nano particles to form a third body layer as a result of mechanical compaction. The best enhancement was at 1\% Wt of Nano particles, 69.9\% and 70.15\% for MoS\textsubscript{2} that added to castor oil and moulding oil respectively. While, the enhancement for CuO is less than that for MoS\textsubscript{2}, approximately about 55\% for both oils. When increasing Nano percentage to 2\%, COF increased too, but less than 1\%. However, CuO values are slightly higher than MoS\textsubscript{2}. It’s attributed to MoS\textsubscript{2} layers in the particles that can easily slide due to weak intermolecular interactions [23].
Figure 8. Effect of Nano particle weight fractions (%Wt) in castor oil and moulding oil on coefficient of friction for particulate lubricants.

The bar chart shown in figure 9 proved the enhancements of Nano-particulate lubricants, especially the hybrid one (1%Wt CuO + 1%Wt MoS$_2$) which gives the lowest COF in both oils. The COF of hybrid Nano-particulate lubricant base castor oil reach to 0.039 with enhancement 81.7% compared to castor oil as a base, while COF of hybrid base moulding oil 0.053 with enhancement 76.03%.

Figure 9. Comparative of COF between both Nano particulate lubricants and their hybrids.

3.3 Wear:
It is observed that, wear developed between the pin and disc using Nano lubricant is much less than that developed using plain oil lubricant. Oils with Nano additives exhibited approximately wear reduction in the range of 82.5% to 93% compared to that of plain oil. Better anti wear properties in the Nano lubricant case is related to the formation of a Tribo film on the contact surface between pin and disc as illustrated schematically in figure 10.
Figure 10. Schematic representation of Wear Test, (a) Pin on disc at rest. (b) Pin on disc in motion. (c) Pin on disc using Nano lubricant.

Figure 11 shows the relation between wear rate and Nano particle weight fractions. Reduction started gradually when increasing Nano concentrations. Wear rate was at lowest case at ratio of 1%W from Nano additives. It can be explained as the lubricant takes place between contacting area and Nano particles spread on surfaces, the particles will carry some of the pressure exerted. Due to Nano superior properties, it will make a separating film between worn surfaces. This thin film will protect the contacted surfaces for much longer causing wear decreasing. Tribo film is considered as a surface coating during friction state. As for the hybrid of 1%W of each Nano particulate powders, wear rate value was at the best giving approximately equally enhancement more than 92% compared to both base oils.

The adding of CuO Nano-particulate powders have more reduction in wear rate compared to MoS$_2$ for both oils about 10% approximately.

Figure 11. Comparison of Wear Rates between both Nano particulate lubricants and their hybrids.

3.4 Micrograph and elemental analysis of wear surface:
The microstructure images of the worn surfaces of pin illustrate the obvious differences in figure 12 between dry, plain oils and hybrid Nano lubricated conditions. Dry case shows the highest damages. Lubricated case shows better results with less wear. Nano lubricated case showed best surface with few defects.
4. Conclusions:
1. The experiments showed a remarkable improvement in operational characteristics of moulding oil and castor oil resulted from the distribution of Nano particles in it.
2. Though the results are encouraging it’s important to study the suspension stability with time.
3. All nanoparticle suspensions exhibited friction and wear reduction compared to the base oil.
4. The anti-wear mechanism of Nano particulate additive produced a Tribo-film of nanoparticles on the wear surfaces, reducing metal-to-metal contact and acting as load-bearing areas.

References:
[1] Sudheerkumar N, et al. 2015 Influence of Nano Solid Lubricant Emulsions on Surface Roughness of Mild Steel When Machining on Lathe Machine Materials Today Proceeding 2 4413-4420.
[2] Allen S and Mahdavian S 2008 The effect of lubrication on die expansion during the deep drawing of axisymmetrical steel cups Journal of materials processing technology 199 102-107.
[3] Shahnazar S, Bagheri S and Hamid S B A 2016 Enhancing lubricant properties by nanoparticle additives International Journal of Hydrogen Energy 41 3153-3170.
[4] Elmunafi M H S, Kurniawan D and Noordin M 2105 Use of castor oil as cutting fluid in machining of hardened stainless steel with minimum quantity of lubricant Procedia CIRP 26 408-411.
[5] Sgroi M, et al. 2017 Engine bench and road testing of an engine oil containing MoS2 particles as nano-additive for friction reduction Tribology International 105 317-325.
[6] Hu Z S, et al. 2002 Preparation and tribological properties of nanometer magnesium borate as lubricating oil additive Wear 252 370-374.
[7] Tan C, et al. 2016 Increase in ironing limit of aluminium alloy cups with lubricants containing nanoparticles Journal of Materials Processing Technology 229 804-813.
[8] Zareh-Desari B M, Abaszadeh-Yakhforvazani and Khalilpourazary S 2015 The effect of nanoparticle additives on lubrication performance in deep drawing process: Evaluation of
forming load, friction coefficient and surface quality *International Journal of Precision Engineering and Manufacturing* 16 929-936.

[9] Mosleh M, et al. 2009 Modification of sheet metal forming fluids with dispersed nanoparticles for improved lubrication *Wear* 267 1220-1225.

[10] Guo D, Xie G and Luo J 2013 Mechanical properties of nanoparticles: basics and applications. *Journal of physics D: applied physics* 47 013001.

[11] Ahmadi H, et al. 2013 Preparation and thermal properties of oil-based nanofluid from multi-walled carbon nanotubes and engine oil as nano-lubricant *International Communications in Heat and Mass Transfer* 46 142-147.

[12] Hwang Y, et al. 2011 Effect of the size and morphology of particles dispersed in nano-oil on friction performance between rotating discs *Journal of Mechanical Science and Technology* 25 2853-2857.

[13] Song X, et al. 2012 Synthesis of monodispersed ZnAl2O4 nanoparticles and their tribology properties as lubricant additives *Materials Research Bulletin* 47 4305-4310.

[14] Sia S, Bassyony E Z and Sarhan A A 2014 Development of SiO2 nanolubrication system to be used in sliding bearings *The International Journal of Advanced Manufacturing Technology* 71 1277-1284.

[15] Bhaumik S, et al. 2018 Analyses of anti-wear and extreme pressure properties of castor oil with zinc oxide nano friction modifiers *Applied Surface Science* 449 277-286.

[16] Wu H, et al. 2018 Friction and wear characteristics of TiO2 nano-additive water-based lubricant on ferritic stainless steel *Tribology International*, 117 24-38.

[17] Borda F L G, et al. 2018 Experimental investigation of the tribological behavior of lubricants with additive containing copper nanoparticles *Tribology International* 117 52-58.

[18] Esfe M H, et al. 2018 Experimental investigation and model development of the non-Newtonian behavior of CuO-MWCNT-10w40 hybrid nano-lubricant for lubrication purposes *Journal of Molecular Liquids* 249 677-687.

[19] Sulieman A M E H 2018 *Gum Arabic as Thickener and Stabilizing Agents in Dairy Products* in *Gum Arabic* Elsevier. p. 151-165.

[20] Reiner E and Radke C 1993 Double layer interactions between charge-regulated colloidal surfaces: pair potentials for spherical particles bearing ionogenic surface groups *Advances in colloid and interface science* 47 59-147.

[21] Rajendhran N, et al. 2018 Enhancing of the tribological characteristics of the lubricant oils using Ni-promoted MoS2 nanosheets as nano-additives *Tribology International* 118 314-328.

[22] Esfe M H and Sarlak M R 2017 Experimental investigation of switchable behavior of CuO-MWCNT (85%–15%)/10W-40 hybrid nano-lubricants for applications in internal combustion engines *Journal of Molecular Liquids* 242 326-335.

[23] Charoo M, et al. 2017 Tribological Properties of MoS2 Particles as Lubricant Additive on EN31 Alloy Steel and AISI 52100 Steel Ball. *Materials Today Proceedings* 4 996.