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Tribological Behaviour of AA1060 Aluminium Alloy with the Aid of Using Nano Lubricant Additives

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ABSTRACT

Nowadays, nanoparticles are extensively employed by mixing them with oils to improve the matting bodies' tribological properties, especially in manufacturing operations that encompass the generation of high temperature, residual stresses and cutting forces that directly affect the engineering part's life, therefore, using nano-lubricated oils becomes a vital tool to reduce these effects. The current investigation is concerned with resolving tribological behavior issues for two lubricant oils, such as 7701 and 144.mg oils, throughout adding different Nanoparticles types. The present study's primary purpose is to explore the tribological behavior of AA1060 aluminum alloy under dry and lubricated conditions by adding various weight percentages of nanoparticles to 7701 and 144.mg oils. molybdenum disulfide (MoS_2) and copper oxide (CuO) nanoparticles with five concentrations vary as follows (0.2, 0.4, 0.6, 0.8, 1.0, and 1.2) %wt. were dispersed in 7701 and 144.mg oils to prepare the nano lubricant additives. This paper's findings reveal a remeakable improvement in coefficient of friction and wear rate due to adding nanoparticles powder to the oil compared to dry and base oil conditions. The optimal condition for coefficient of friction and wear rate was observed at 1%wt. of both nanoparticles and hybrid lubricant additives.

KEYWORDS

Wear, Coefficient of friction, Nanoparticle additives, Hybrid lubricant, Aluminium alloy

INTRODUCTION

Tribology is known as the technology and science of moving bodies related to lubrication, friction and wear [1]. Lubrication method is the technique or operation to diminsh the friction and wear for moving surfaces through employing different types of lubricants [2]. Friction and wear conditions might cause different types of failure in machine parts such as failure in shafts, engines, gears, bearings and above that all can cause losses of energy [3]. Numerous studies were carried out on friction, wear, and lubrication. Shahnazar found that nanoparticles' addition to base oils is a vital tool to imorving specified types of properties such as wear resistance and friction [4]. Handawi concluded that using a certain amount of lubricant of 50 ml/h during turning operation contribute in good outcomes in comparison with dry conditions, moreover, longer tool life results reveal a slight improvement in the surface roughness and cutting forces [5]. Zareh-Desaria B and Davoodi B Mixed two types of nanoparticels such as SiO_2 and CuO in rapeseed and soybean oils with various weight perecentages [6]. The finding shows that when increasing nanoparticles' concentration, the generating friction and deformation force arrive a lowest value for a certain amount of weight percentage. Dinesh noticed that MWCNTs and Zinc Oxide nanoparticles with different weight percentages such as 0.005%, 0.02% give a remarkable enhancement in the lubrication thermal and physical characteristics compared to base oil [7]. Hussain investigated UHMWPE's tribological performance under bio serum lubrications when rubbing with 316L stainless steel, and the results exhibit that the optimum tribological performance was achieved when using Ti6Al4V as a counterface material type with human serum and the applied force equal 52 N [8]. Manzoor noticed that the coefficient of friction and wear rate reduced with a rise in load applied for ceramic composite and silicon nitride specimens under dry conditions [9]. Furthermore, the findings exhibit the Si3N4 with 2 % wt. of TiC composite owns best tribological properties. Xia developed a new type of lubricant based on oil and water (O/W) and mixed it with nanoparticles lubricants which containing TiO_2 nanoparticles to enhance the surface finish of AISI 304 stainless steel and reduce the rolling force [10]. Charoo investigated the particle size impact of MoS_2 on the tribological behaviour of EN31 steel disc and AISI 52100 steel ball [11]. The Nanoparticles mixed with SAE 20W40 as a lubricant condition. The results indicate that when the particle size decreases, the wear and coefficient of friction decrease. Bhaumik noted that the addition 0.1% of ZnO nanoparticles resulted in enhancement the wear and extreme pressure properties and above this weight percentage the coefficient of friction improvement would not considerably amount but the wear rate rised [12]. Kumar noted that when spraying the AL_2O_3 Nanopowder on the surface throughout the machining process, forming a thin layer on the surface which results in enhancement and changing the properties such as the surface roughness and hardness [13]. Popovic used Titanium nitride (TiN) prepared by D.C. sputtering and irradiated silver (Ag) ions, and the results show that the irradiations drive to lattice deformation, rising disorder and produce a new phase of silver (Ag) [14]. Namer investigated the influence of adding nanoparticles to the different types of lubricant oils on the tribological characteristics for AA2024-T4 aluminum alloy covered by SiN and TiN thin films [15]. They found a good improvement in friction and wear rate due to using Nanoparticle additives. Namer studied the impact of oil viscosity on the quality of formed parts [16]. They noticed a remarkable enhancement of the product as a consequence of increasing the oil viscosity. Mezher adopted an experimental and numerical investigation on the influence of nanoparticles additive on the formed parts accuracy by utilizing different forming processes [17, 18]. The findings revealed a noticeable betterment in the quality of the final products owing to employing Nanopowder. Kogovsek J and Kalin M analyzed the impact of using WS_2 and MoS_2 with micro and nanoparticles [19]. They concluded that MoS_2 has better results in comparison with WS_2. Gulzar applied a experimental investigation of MoS_2 and CuO nano powders impact in regared to the tribological properties [20]. They found that the MoS_2 shows a notable change in the tribological performance as compared to CuO. Xie evaluated the tribological behavior of SiO_2/MoS_2 hybrid nanoparticles with various concentrations [21]. They noticed that utilizing SiO_2/MoS_2 as hybrid additives gives a marked enhancement in lubrication properties than using MoS_2 or SiO_2 as individual nanoparticles. Xu analyzed the friction and wear behaviour using micro and nanoparticles of MoS_2 Nanopowder [22]. The results indicate that utilizing nanoparticles enhances the tribological properties better than microparticles. Mezher explored the influence of forming conditions in regard to the formability properties of AA1050 aluminium alloy and DC05 carbon steel [23]. Two papers investigated the shear strength of welded joints by applying different welding processes [24, 25]. The current work focuses on the tribological behaviour of AA1060 aluminium alloy by scrutinizing the impact of adding different MoS_2 and CuO nanoparticles to the 7701 and 144.mg oils. Furthermore, a hybrid nanoparticle containing the ideal concentration of each nanoparticle was mixed with 7701 and 144.mg oils to examine its impact on coefficient of friction and wear rate.

EXPERIMENTAL WORK

Samples preparation

AA1060 aluminum alloy as a cylindrical pin with dimensions (5×16) mm, and CK 45 material as a disc with 16 mm inner diameter, 32 mm outer diameter and 11mm thickness as shown in figure 1, which were employed as a specimen in the current study. The chemical composition is summarized in table 1.

Figure 1. Pin and disc specimens.

Table 1. Chemical Composition of AA1060 aluminum alloy

Item %	Si	Mn	Mg	Cu	Zn	Fe	other	Al
/	0.055	0.007	0.0001	0.005	0.011	0.02	0.02	Balance

Preparation of nano lubricants

The commercial engine oil grades of 7701 and 144.mg available at Al-Dura Refinery mixed with different concentrations (0.2, 0.4, 0.6, 0.8, 1.0, and 1.2%) wt.% of MoS_2 and CuO nanoparticles. The original viscosity of the 7701and 144.mg oils were 15.37 and 124.35 Pascal×sec, respectively, at room temperature. The most common problem in nanoparticles when it is mixed with lubricants oil is the dispersion stability. It well-known nanoparticles possess high surface energy value owing to their high surface to volume ratio and these nano powders in oil suspension might be agglomerated to each other. The dispersion stability plays an indispensable function in conserving the properties and performance of nano lubricant oil. Consequently, a direct influence on wear rate and friction coefficient increases the dispersibility and stability of nanoparticles in lubricant oils and reduces these particles' agglomeration. The sonication device is used for 30 minutes at 50°C. Figure 2 depicts some of the nanoparticle-oil suspension samples. The characteristics of nanopowder (MoS_2 and CuO) ordered from the company are listed in table 2. The XRD inspection for these nanoparticles are depicted in figure 3.

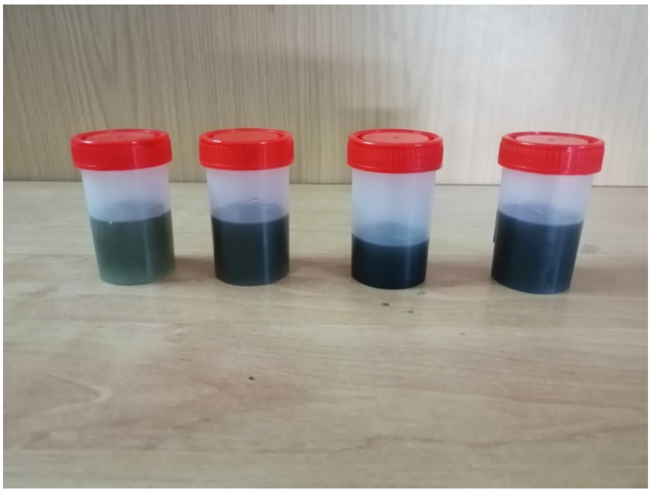

Figure 2. Samples of some nanoparticle-oil suspension

Table 2. Information of nanoparticles

Supplier Information	MoS_2	CuO
Place of origin	Seabrook, NH, U.S.A.	Henan. China (Mainland)
Company	AESAR, A BRANCH OF JOHNSON MATHEY -INC	ZHENGZHOU DONGYAO NANOMATERIALS CO., L.T.D.
Standard of Grade	Industrial Grade	Electron and Industrial Grades
Average Particle size (nm)	60	55
Purity (%)	99.9	99.9

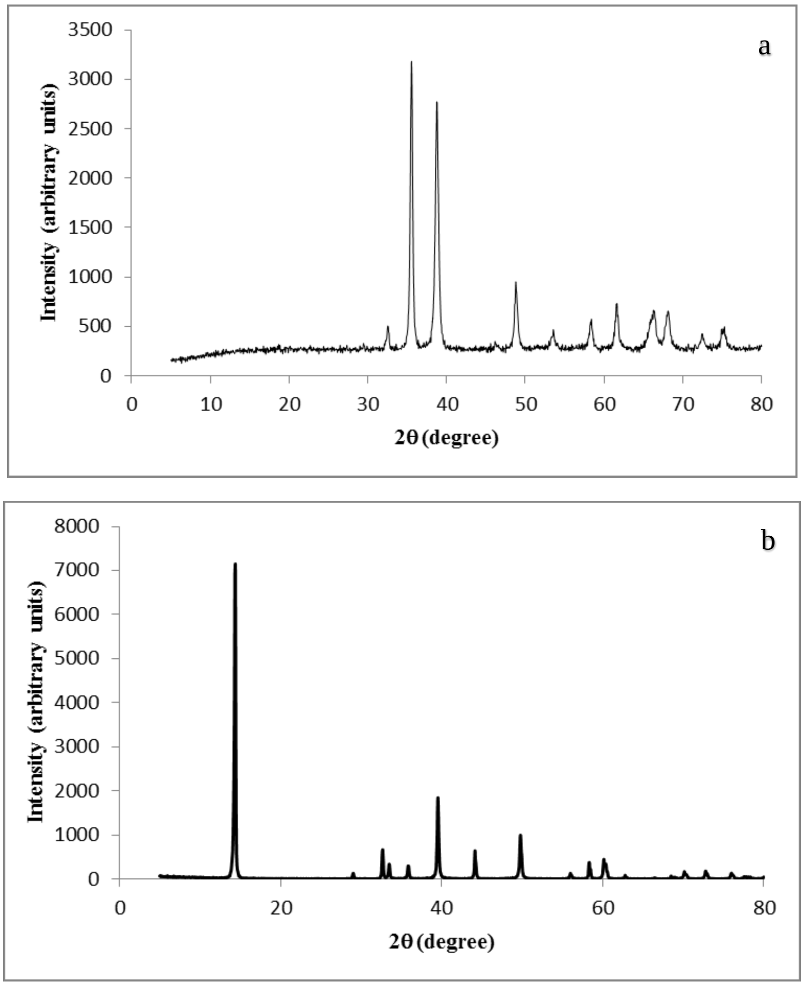

Figure 3. (a) XRD of CuO nanoparticles; (b) XRD of MoS_2 nanoparticles

Friction and wear test

A pin on disc test arrangement is employed in regard to explore the variation in tribological behavior between AA1060 aluminum alloy pin and CK45 disc by adding various CuO and MoS_2 nanoparticle concentrations to 7701 and 144.mg oils. In the current work, wear and friction experiments were performed by employing vertical universal friction testing machine (MMW-1A), and the carried out of all tests are at room temperature. Preliminary tests with wet and dry conditions at various loads (100, 120, 140, 160, and 180 N) had been performed to assess the perfect applied load, which results from the minimum wear rate and coefficient of friction. Later on, the optimum applied force is employing to conduct the wear and friction tests for AA1060 aluminum samples with different weighted nano additive particles. The other experimental parameters were the testing time equal 720 second and sliding speed equal 1.5176 m/s. Wear loss values were measured by employing precision balance through weghining the pin samples before and after each experiment, based on ASTM G99 standard and using the equation that derived in [26].

WR= $\frac{\Delta W}{SD}$

Where:

WR: Wear rate (gm/cm),
ΔW: Variation in weight before and after each experiment (gm),
SD: Sliding distance (cm).

RESULTS AND DISCUSSION

Coefficient of friction

In regard to obtain the friction coefficient under dry and lubricated conditions, experiments were carried out at testing time 720 sec, sliding speed 1.5176 m/s and room temperature. Figure 4 portrays the variation in coefficient of friction for AA1060 aluminum alloy of different loads at wet and dry conditions in the existence of 7701 and 144.mg oils. The results suggest that 144.mg oil gives the highest enhancement in the friction coefficient, reaches up to 46.57% compared to dry conditions at the same applied loads. In contrast, it was 26.13% for 7701 oil. It is worth noticing that a more significant improvement in friction conditions with 144mg oil is attributed to its higher viscosity than 7701 oil. Oil viscosity is substantial because it is directly related to load resistance. The higher viscosity of the oil, the more excellent resistance to applied loads. 144.mg oil has high viscosity than 7701 oil; this makes it more heat tolerant and does not lose its properties quickly, giving more resistance to friction than 7701 oil.

Figure 5 displays the impact of the addition of CuO and MoS_2 nanoparticles to 7701 and 144.mg oils on the coefficient of friction for AA1060 aluminum alloy specimens. It is worth noticing that the coefficient of friction reduces as a consequence of the increasing in nanoparticles' weight percentages up to 1% wt. It considers the optimal value of these added concentrations. At this point, the recorded friction coefficient is the lowest value for both MoS_2 and CuO nanoparticles. Afterward, the weight percentage was 1.2%wt., the coefficient of friction start to increase significantly. Another interesting observation is that 144.mg oil demonstrates a superior coefficient of friction results than 7701 oil. It was noticed that the enhancement in coefficient of friction due to the use of MoS_2 and CuO reaches up to 40.27% and 27.82%, respectively, when compared to 144.mg oil without nanoparticles.

In contrast, it was at the same conditions for CuO 32% and 19% compared to 7701 oil without additives. Thus, it can be concluded that the type of nanoparticles can explain the improvement in friction coefficient due to using nanoparticles. For CuO nanoparticles, the film thickness in the lubrication oil between the mating bodies and this film acts as a adsorbed film between the contact bodies and acts as a ball-bearing impact that helps decrease the coefficient of friction. While for MoS_2 nanoparticles, it produces tribo-film between the contact bodies, which provides protective film, reducing friction. A hybrid of 1% CuO and 1% MoS_2 was added to 7701 and 144.mg to investigate its impact on coefficient of friction, the results indicate that the hybrid nanoparticles lubricant additive decrease the coefficient of friction value to 0.0743 for 7701 oil and 0.0562 for 144.mg oil, the improvements due to employing hybrid nanoparticles additive were 49.8% and 58.5% respectively in comparison with results of using only 1% MoS_2 or 1% CuO with 7701 oil. Otherwise, the achieved enhancements with 144.mg oil due to using hybrid nanoparticles additive were 53.2% and 61.2% respectively of MoS_2 and CuO nanoparticels at the same conditions.

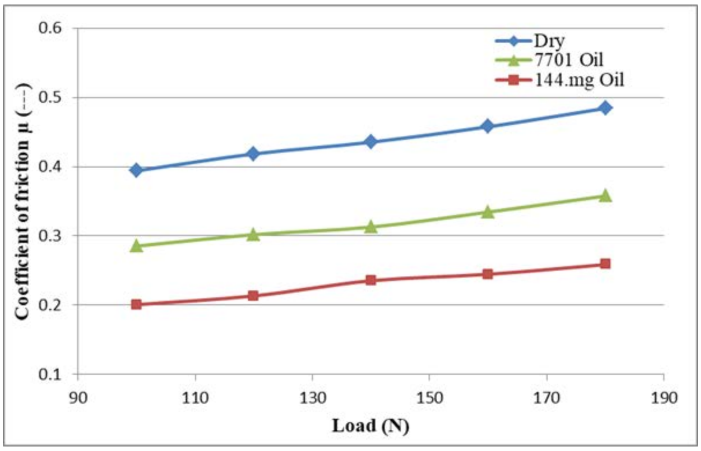

Figure 4. Variation in the coefficient of friction to the applied load

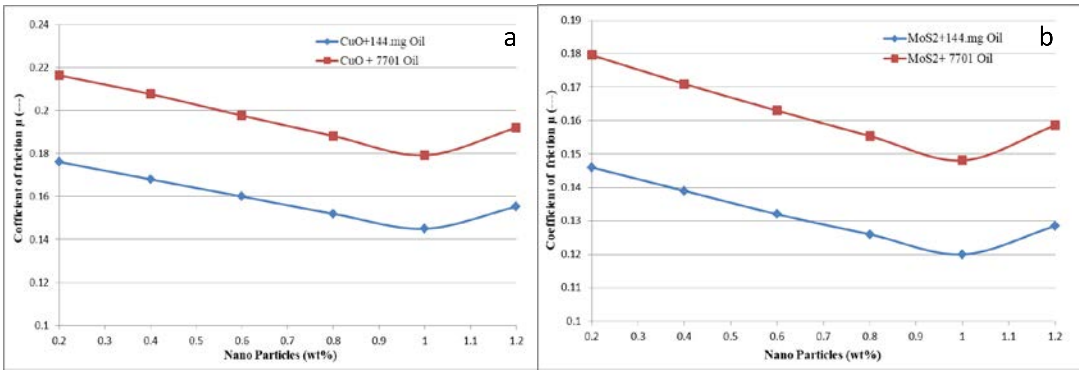

Figure 5. Variation in coefficient of friction with adding nanoparticles, (a) CuO, (b) MoS_2

Wear rate

The calculated quantitative wear through weighing AA1060 specimens was utilizing high precision digital balance before and after every experiment. Figure 6 presents the influence of employing lubricants on the wear rate of AA1060 aluminum alloy compared with dry conditions. The enhancement in wear rate when utilizing144.mg and 7701 oils reach 50.12% and 40.69%, respectively. 144.mg oil shows a minimum wear rate in comparison with 7701 oil due to the higher viscosity of 144.mg oil. As mentioned previously, when the viscosity increases, the coefficient of friction is directly reducing correlates with wear rate. Figure 7 explains the influence of utilizing oils with nanoparticles on the wear rate. As observed from figure 7, the wear rate reduces when the concentrations of nanoparticles increase until it reaches 1% wt. of both nanoparticles, which deems the optimal value.

The addition of MoS_2 and CuO to 144.mg oil decreased the wear rate to 81.65% and 72.3%, respectively, compared to utilizing 144.mg oil without additives. In contrast, it was at the same conditions, 69.45 % for MoS_2 and 58.23% for CuO, respectively, compared to 7701 oil without additives. The improvement at this percentage is due to the formation of tribo-film, also the adherence and adsorption of nanoparticles over the contact bodies that contributed to decreasing the wear properties. As well, the very small size of these nano powders assist them penetrate inside the mating bodies, and therefore the wear and friction properties decreased. When the concentration of nanoparticles increased by more than 1%wt reaches 1.2%wt., the wear rate increases due to the film thickness getting bigger. This will contributes to more heat generation instability between the mating bodies (i.e., pin and disc surfaces).

Another interesting point is that the MoS_2 reveals a more remarkable improvement in decreasing wear rate than CuO, as shown in figure 7. The higher enhancement when using MoS_2 in comparison with CuO is attributed to the shape of nanoparticles. The MoS_2 has a lamellar shape, making it better lubricant additives, moreover, the exfoliation occurs between the mating surfaces under the applied shear stress, and thus wear rate decreased. Also, the structure of MoS_2 is hexagonal, which helps layers cut off during the applying of loads and hence produce a protective film layer on the surface which reduces the wear rate. CuO has a spherical shape, and the surface energy is equal for all regions. The CuO nanoparticles act as a ball-bearing influence when they roll between the contact bodies and decrease the wear and friction properties but not as much as MoS_2 does. Once more, the hybrid nanoparticles was used to analyse its effect on the wear rate, the obseravations of the findings reveal that the wear rate value reduced up to 1.62×10^{-9} gm/cm for 7701 oil and 9.21×10^{-10} gm/cm for 144.mg oil, the betterments through using hybrid nanoparticles lubricant were 23.9% and 36.5% respectively as compared with utilizing only 1% MoS_2 or 1% CuO mixed with 7701 oil. In contrast, the hybrid nanoparticles with 144.mg oil gave improvements reach up to 43.5% and 46.7% repectively of MoS_2 and CuO nanoparticels at the identified conditions.

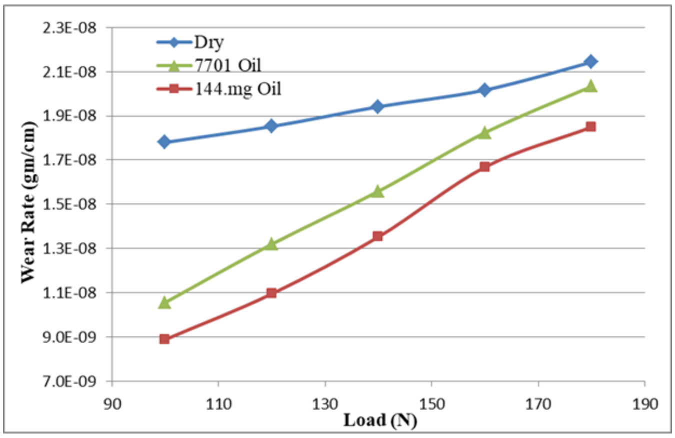

Figure 6. Effect of applied load on the wear rate

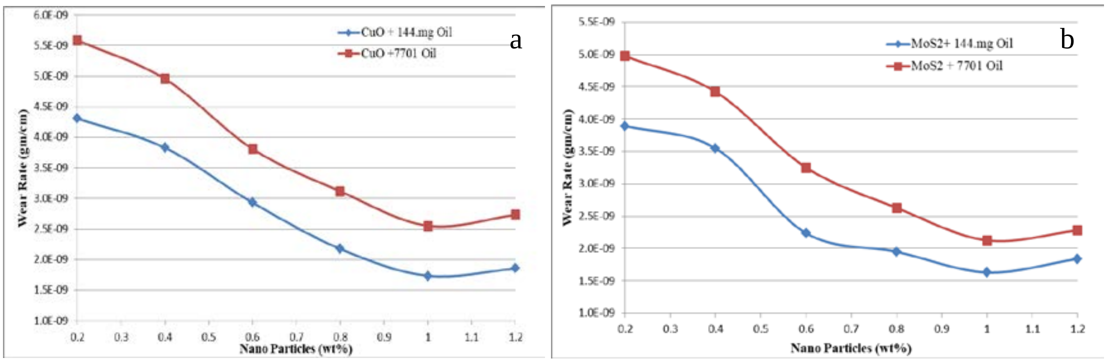

Figure 7. Variation in wear rate with adding nanoparticles, (a) CuO, (b) MoS_2

CONCLUSION

In this study, the experimental exploring of the tribological behaviour of AA1060 aluminum alloy pins and CK45 disc conducted by adding two types of nanoparticles to the base oil. The main conclusions from this work as follow:

1- The coefficient of friction and wear rate decreases with increasing the applied load for dry and lubricated conditions.
2- Wear rate and coefficient of friction improved noticeably due to dispersing nanoparticles in 7071 and 144.mg oils.
3- 144.mg oil exhibits better observation with various weight percentages of nanoparticle additive than 7701 oil.
4- MoS_2 and CuO nanoparticles were useful additive for reducing the friction and wear properties by forming tribo-film thickness between the rubbing surfaces.
5- MoS_2 exhibits better improvement in wear rate and coefficient of friction than CuO nanoparticles.
6- Employing hybrid nanoparticle lubricants demonstrates the best enhancement in tribological behaviour.

REFERENCES

[1] W.J. Bartz, "Tribology, lubricants, and lubrication engineering-A review," *Wear*, Vol. 49 No.1, Pp.1–18, 1978.

[2] H.M. Mobarak, E.N. Mohamad, H.H. Masjuki, M.A. Kalam, K.A.H. Al Mahmud, M. Habibullah and A.M. Ashraful, "The prospects of biolubricants as alternatives in automotive applications," *Renewable and Sustainable Energy Reviews*, Vol. 33, Pp. 34–43, 2014.

[3] K. Holmberg, P. Andersson and A. Erdemir, "Global energy consumption due to friction in passenger cars," *Tribology International*, Vol. 47, pp. 221–234, 2012.

[4] S. Shahnazar, S. Bagheri and S.B. Abd Hamid, "Enhancing lubricant properties by nanoparticle additives," *International journal of hydrogen energy*, Vol. 41, No. 4, 2015, Pp. 3153-3170, 2016.

[5] M.H.S. Elmunafi, D. Kurniawan and M.Y. Noordin, "Use of Castor Oil as Cutting Fluid in Machining of Hardened Stainless Steel with Minimum Quantity of Lubricant," *Procedia CIRP*, Vol. 26, Pp. 408-411, 2015.

[6] B. Zareh-Desaria and B. Davoodi, "Assessing the lubrication performance of vegetable oil-based nano-lubricants for environmentally conscious metal forming processes," *Journal of Cleaner Production*, Vol. 135, Pp. 1198-1209, 2016, DOI: 10.1016/j.jclepro.2016.07.040.

[7] R. Dinesh, M.J. Giri Prasad, R. Rishi Kumar, N. Jerome Santharaj, J. Santhip and A.S. Abhishek Raaj, "Investigation of Tribological and Thermophysical Properties of Engine Oil Containing Nano additives," *Materials Today: Proceeding*, Vol. 3, No. 1, Pp. 45-53, 2016.

[8] O. Hussain, S.S. Saleem, and B. Ahmad, "Friction and wear performance evaluation of UHMWPE using Taguchi based grey approach: A study on the influence of load and bio-serum lubrication," *Materials Chemistry and Physics*, Vol. 239, 121918, Pp. 1-9, 0254-0584, 2020.

[9] S. Manzoor, M.F. Wani and S.S. Saleem, "Effect of load on the friction and wear behaviour of silicon nitride and silicon nitride titanium carbide ceramic composite," *Materials Today: Proceeding*, Vol. 19, Part 2, Pp. 474-477, 2019.

[10] W. Xiaa, J. Zhao, H. Wua, X. Zhao, X. Zhang, J. Xu, S. Jiao, X. Wang, C. Zhou and Z. Jianga, "Effects of oil-in-water base nanolubricant containing TiO_2 nanoparticles in hot rolling of 304 stainless steel", *Journal of Materials Processing Technology*, Vol. 262, Pp. 149-156, 2018.

[11] M.S. Charoo, M.F. Wani, M. Hanief and M.A. Rather, "Tribological Properties of MoS_2 Particles as Lubricant Additive on EN31 Alloy Steel and AISI 52100 Steel Ball", *Materials Today: Proceeding*, Vol. 4, No. 9, Pp. 9967-9971, 2017.

[12] S. Bhaumik, R. Maggirwar, S. Datta and S.D Pathak," Analyses of Anti-wear and Extreme Pressure Properties of Castor Oil with Zinc Oxide Nano Friction Modifiers," *Applied Surface Science*, Vol. 449, Pp. 277-286, 2018.

[13] N. Sudheerkumar, P. Sammaiah, K. Venkateswara Rao, M. Sneha, and C.H. Ashok, "Influence of Nano Solid Lubricant Emulsions on Surface Roughness of Mild Steel When Machining on Lathe Machine," *Materials Today: Proceedings*, Vol. 2, No. 9, Part A, Pp. 4413-4420, 2015.

[14] M. Popovic', M. Novakovic', Z. Rakocˇevic and N. Bibic, "Tailoring the structural and optical properties of TiN thin films by Ag ion implantation," *Nuclear Instruments and Methods in Physics Research B*, 389–390, Pp. 33-39, 2016. DOI: http://dx.doi.org/10.1016/j.nimb.2016.11.013.

[15] N.S.M. Namer, S.A. Nama, and M.T. Mezher, "The influence of Nanoparticles additive on tribological properties of AA2024-T4 coated with TiN or SiN thin films", *Journal of Mechanical Engineering Research and Developments (JMERD)*, Vol. 42, NO. 3 Pp. 30-34, 2019. DOI: http://doi.org/10. 26480/jmerd.03.2019.30.34.

[16] N.S.M. Namer, S.A. Naáma and M.T. Mazhir, “Influence of Lubricant Viscosity on the Surface Roughness of PEHD and PVC Plastic Sheets in Single Point Increment Forming Process”, *International Journal of Engineering and Applied Sciences*, Vol. 7, No. 2, Pp. 27-30, 2015.

[17] M.T. Mezher, M.L. Saad, O.S. Barrak and R.A Shakir, "Finite Element Simulation and Experimental Analysis of Nano Powder Additives Effect in the Deep Drawing Process," *International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS*, Vol. 20, No. (01), Pp. 166-180, 2020.

[18] M.T. Mezher, N.S. Namer and S.A. Nama, "Numerical and Experimental Investigation of Using Lubricant with Nano Powder Additives in SPIF Process," *International Journal of Mechanical Engineering and Technology*, Vol. 9, No. 13, Pp. 968-977, 2018.

[19] J. Kogovšek and M. Kalin, "Various MoS_2, WS2 and C based micro and nanoparticles in boundary lubrication", *Tribology Letters*, Vol. 53, No. 3, Pp. 585-597, 2014, DOI: 10.1007/s11249-014- 0296-1.

[20] M. Gulzar, H.H. Masjuki , M. Varman, M.A. Kalam, R.A. Mufti, N.W.M. Zulkifli, and R.Y.R. Zahid, "Improving the AW/EP ability of chemically modified palm oil by adding CuO and MoS_2 nanoparticles", *Tribology International*, Vol. 88, Pp. 271–279, 2015, DOI: http://dx.doi.org/10.1 01 6/j.triboi nt.20 15.03. 035.

[21] H. Xie, B. Jiang, B. Liu, Q. Wang, J. Xu and F. Pan, "An Investigation on the Tribological Performances of the SiO_2/MoS_2 Hybrid Nanofluids for Magnesium Alloy-Steel Contacts", *Nanoscale Research Letters*, Vol. 11, Article No. 329, 2016, DOI: 10.1186/s11671-016-1546-y.

[22] Y. Xu, E. Hu, K. Hu, Y. Xu and X. Hu, "Formation of an adsorption film of MoS_2 nanoparticles and dioctyl sebacate on a steel surface for alleviating friction and wear", *Tribology International*, Vol. 92, Pp. 172–183, 2015. DOI: http://dx.doi.org/10.1016/j.triboint.2015.06.011.

[23] M.T. Mezher, O.S. Barrak, S.A. Nama, and R.A. Shakir, "Prediction of Forming Limit Diagram and Spring-back during SPIF process of AA1050 and DC04 Sheet Metals", *Journal of Mechanical Engineering Research and Developments*, Vol. 44, No. 1, Pp. 337-345, 2021.

[24] O.S. Barrak, M.L. Saad, M.T. Mezher, S.K. Hussein and M.M. Hamzah, "Joining of Double Pre-Holed Aluminum Alloy AA6061-T6 to Polyamide PA using Hot Press Technique". *In I.O.P. Conference Series: Materials Science and Engineering*, Vol. 881, No. 1, Pp. 012062. I.O.P. Publishing, 2020.

[25] M.T. Mezher, M.L. Saad, O.S. Barrak, S.K. Hussein and R.A. Shakir, "Multi-coupled Field Simulation and Experimental Study of AISI 316L Stainless Steel using Resistance Spot Welding" *Journal of Mechanical Engineering Research and Developments*, Vol. 44, No. 2, Pp150-160, 2021.

[26] N. Rajendhran, S. Palanisamy, P. Periyasamy and R. Venkatachalam, "Enhancing of the tribological characteristics of the lubricant oils using Ni-promoted MoS_2 nanosheets as nano-additives" *Tribology International*, 2017, doi: 10.1016/j.triboint.2017.10.001..