Jurnal Tribologi 43 (2024) 169-184

MYTRIBOS
Malaysian Tribology Society

Jurnal Tribologi
Website : jurnaltribologi.mytribos.org
e-issn: 2289-7232

Assessment of lubricant performance enhanced with nanoadditive in punching and blanking of aluminium

Muhammad Shuhaimi Ibrahim, Mohd Hafis Sulaiman *

Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, Serdang, MALAYSIA.
*Corresponding author: hafissulaiman@upm.edu.my

KEYWORDS

Blanking
Punching
Fracture
Nano additive
Lubrication

ABSTRACT

The pickup of aluminum workpieces on the punch surface leads to poor product quality and dimensional accuracy, thereby reducing tool life. These drawbacks are commonly mitigated by applying an abundant number of lubricants. To reduce the large consumption of lubricants, which is harmful to human health and the environment, this study presents an investigation of nanoadditives (MgO, SiC, TiO2, and MgO/SiC) added to paraffin oil, and the properties of the formulated lubricant were studied. Punching and blanking of aluminum were used to understand the performance of the formulated lubricants. Among the additives studied, MgO demonstrated a significant reduction in forward and backward forces, revealing the least amount of fracture zones on the workpiece. This suggests that MgO holds promise as an effective and efficient additive for enhancing lubrication performance in punching and blanking operations.

1.0 INTRODUCTION

Sheet metal forming often uses blanking and punching, which are the primary methods of cutting, and it is often integrated with additional forming procedures either as an intermediate or final step in production (Lind et al., 2015). Punches experience severe contact conditions, including high contact pressures and dynamic impact loads (Daniel et al., 2020). Increasing punch longevity can be achieved through a variety way, such as optimizing fine blanking tools to reduce stress (Sergejev et al., 2011) and applied the lubricant to reduce the dynamite coefficient of friction between the tool and workpiece (Mulyadi et al., 2022). Evaluating the effectiveness of a lubricant in drilling involves calculating the coefficient of friction (COF) based on backstroke force

Received 19 August 2024; received in revised form 18 September 2024; accepted 12 October 2024.
To cite this article: Ibrahim and Sulaiman (2024). Assessment of lubricant performance enhanced with nanoadditive in punching and blanking of aluminium. Jurnal Tribologi 43, pp.169-184.

measurements and analysing the theoretical stress applied to the drilling surface (Moghadam et al., 2020). This is because the wear of the punch leads to various defects during the cutting process. Errors in punching, such as dimensional, positional, shape and surface inaccuracies (Hernández et al., 2006) are produced and directly affect the quality of the pieces (Monteil et al., 2008). Frequent errors include issues such as edge strain, crack penetration depth and burr height (Hambli, 2002). Adding additives to the base oil has the potential to significantly reduce friction and provide exceptional anti-wear properties in the friction pair (Duan et al., 2019). Additives can now be categorized into four types: organic friction modifiers, functional polymers, oil-soluble organic additives, and nanomaterials (Spikes, 2015).

Nanolubricants refer to the particles of nanometer dimensions, usually ranging from a few nanometers to 0.1 mm in diameter, exhibiting intriguing tribological properties akin to solids (X.-B. Wang & Liu, 2013). Particles of different composition and size have shown varying degrees of effect on friction and wear, displaying a certain degree of modification (Y. Chen et al., 2019). Many researchers study the efficiency of the lubricant that involve variety of nanometarials such as graphene (Liu et al., 2022; B. Yu et al., 2022), layered double hydroxide (K. Wang et al., 2020; Zhou, Li, Liu, Zhan, et al., 2022), MXenes (T. Chen et al., 2022; Zhou, Li, Liu, Ma, et al., 2022), and many more. This is due to its comparatively large specific surface areas, limited interlayer interactions, and impressive lubrication properties (Liu et al., 2023). Chouhan and et. al (Chouhan et al., 2020) studies a hybrid material consisting of ZnO-decorated reduced graphene oxide/MoS2 was created to improve the tribological characteristics of engine oil. The resulting hybrid, even in small amounts, demonstrated a notable decrease in both coefficient of friction (COF) and wear volume by 37% and 87%, respectively. Dai et al. (Dai et al., 2016) introduce the nanoparticles in the boundary lubrication area which can lead to a decrease in the friction coefficient of up to 70% and a significant reduction in the amount of wear, reaching as high as 75%. Lubricants consisting of base oil and dispersed nanoparticles have emerged as a new category of nano-lubricants (Gulzar et al., 2016). Nanoparticles increase lubricant stability, leading to reduced friction and wear on components. Different nanoparticles such as Al2O3, CuO, MgO, etc. have been incorporated for this purpose. Magnesium oxide exhibits superior properties due to its high solubility and lower density (Singh et al., 2021). Several studies were be done with nanoparticle in lubricant. Mahara et al. (Mahara & Singh, 2020) conducted research on neem oil, incorporating SiC as an additive. The result was the achievement of effective lubrication through its application. Additive TiO2 was used in lubricant and leads to reduced wear of ball specimens. Compared to the pure lubricant, the inclusion of 0.075% TiO2 improved the performance of the lubricant, as evidenced by a higher flash temperature (FTP) parameter and obtained COF of 0.01 by used oil sample that contain 0.075 wt.% TiO2 at 75 °C lubricant lubrication (Birleanu et al., 2022).

The quality of the finished product and the durability of the tooling are both critically dependent on proper lubrication and tool wear during the metal forming processes of blanking and punching. Despite its significance, the impact of lubrication and tool wear on the punching and blanking process has received little attention in study and analysis (Moghadam et al., 2020). Insufficient lubricant quality causes heavy pick-up of workpiece material on the punch, which results in poor surface quality, decreased dimensional accuracy, and a shorter tool life. Therefore, this study focuses on the performance of different nanoadditives in oil-based lubricants used in punching and blanking processes. The study examines the maximum force required to punch the sample, and the effect on the workpiece sample. To conduct the study, the researchers used a punching setup with a punching tool, die, and aluminum sheet as a workpiece. Each sample of nanoparticle additive (MgO, SiC, MgO/SiC, and TiO2) was punched 50 times to assess its performance.

2.0 EXPERIMENTAL PROCEDURE

Paraffin oil was used as the basic lubricant in this study. Three types of nanoparticles have been used to create nano-lubricants: 20-30 nm Magnesium oxide (MgO) with 99% purity, 5-10 nm Titanium dioxide (TiO2) with 99.3% purity, both obtained from Jiansu XFNano Materials, and 40 nm Silicon carbide (SiC) obtained from Xi'an LY Health Technology CO. Polyvinylpyrrolidone (PVP), and Sodium Lauryl Sulfoacetate (SLSA) were used as surfactants to increase viscosity and ensure a stable nanoparticle dispersion.

2.1 Preparation Method of The Test Lubricants

Sodium Lauryl Sulfoacetate (SLSA) and paraffin oil were combined using magnetic stirring. Subsequently, Polyvinylpyrrolidone (PVP) was gradually introduced into the solution while continuing magnetic stirring. Following this, the solution was incrementally supplemented with nanoparticles. After an additional 45 minutes, any remaining agglomeration was eliminated through ultrasonication. The nano-lubricants were prepared by dispersing nanoparticles by a two-step method (Ilyas et al., 2014; Kong et al., 2017; W. Yu & Xie, 2012). The parameter condition of the MAGNETIC STIRRER (M1): Speed (1200 rpm), and duration (120 minutes); Ultrasonication (M2); Speed (13000 rpm), Dduration (45 minutes), power input (800 W), and frequency (50/60 Hz). The development of the test lubricants utilized a two-step method as illustrated in Figure 1. In Table 1, the additive concentrations in the test lubricants are outlined.

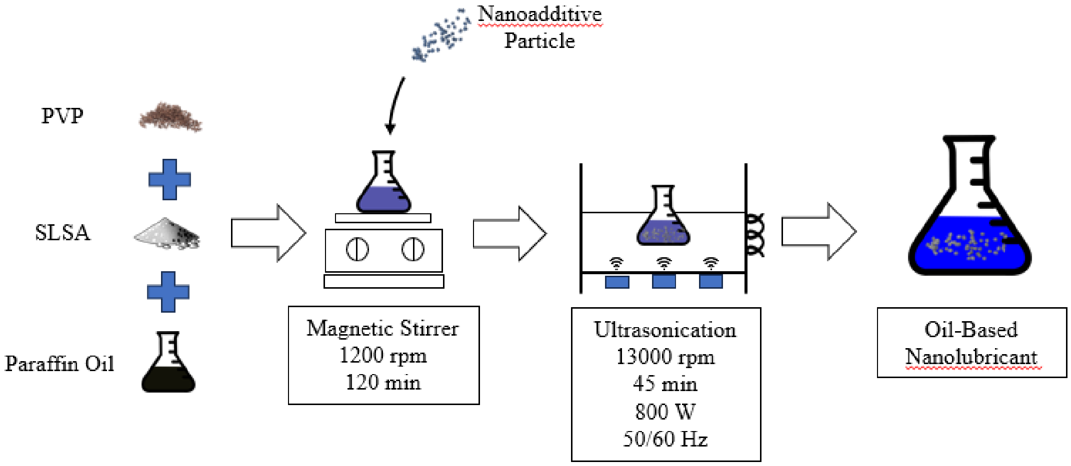


Figure 1: Flow chart of preparation of the test lubricants.

2.2 Dispersion Stability of Nanoparticle in Formulated Lubricants

Sedimentation method was used to assess the dispersion stability of nano-lubricant (Choi, 2022). This method was observed by collecting each sample of nano-lubricant with 50 ml into the vials and placed at room temperature without moving the sample. The sample was monitored daily until the nanoparticles settled at the bottom of the vials, and a clear separation between the nanoparticles and the oil became apparent. The dispersion stability of nanoparticle in oil can be assessed based on the distribution and agglomeration of nanoparticle under observation. This method represents a fundamental and cost-effective approach to analyse the stability of nano-lubricant dispersions (Morshed et al., 2021). The concentration is measured using the following formula, with the total weight being 200 grams.

$$wt\% = \left(\frac{W_{additive}}{W_{total}}\right) \times 100$$

Therefor,

$$W_{additive} = \frac{wt\% \ \times W_{total}}{100}$$

Table 1: Formulations of test lubricants.

Sample	Content
1	Paraffin oil
2	0.5 wt% MgO nanoparticles + 10 wt% SLSA + 0.05 wt% PVP + paraffin oil
3	0.5 wt% SiC nanoparticles + 10 wt% SLSA + 0.05 wt% PVP + paraffin oil
4	0.3 wt% MgO nanoparticles + 0.2 wt% SiC nanoparticles + 10 wt% SLSA + 0.05 wt% PVP + paraffin oil
5	0.5 wt% TiO_2 nanoparticles + 10 wt% SLSA + 0.1 wt% PVP + paraffin oil

2.3 Size of Nanoparticle in The Test Lubricants

The size and shape of nanoparticles can be distinguished using microscopic techniques such as transmission electron microscopes (TEM) because of its excellent resolution, electron microscopy is now the technique that is most frequently used to assess the stability of nanoparticles in a base lubricant. This techniques for examining the morphology and size distribution of nanoparticle. A drop of nano-lubricant is deposited on a carbon-coated copper grid and left at room temperature until the base lubricant has completely evaporated. After that, the samples were examined using an optical microscope (OM) to observe the agglomeration of nanoparticles in each sample.

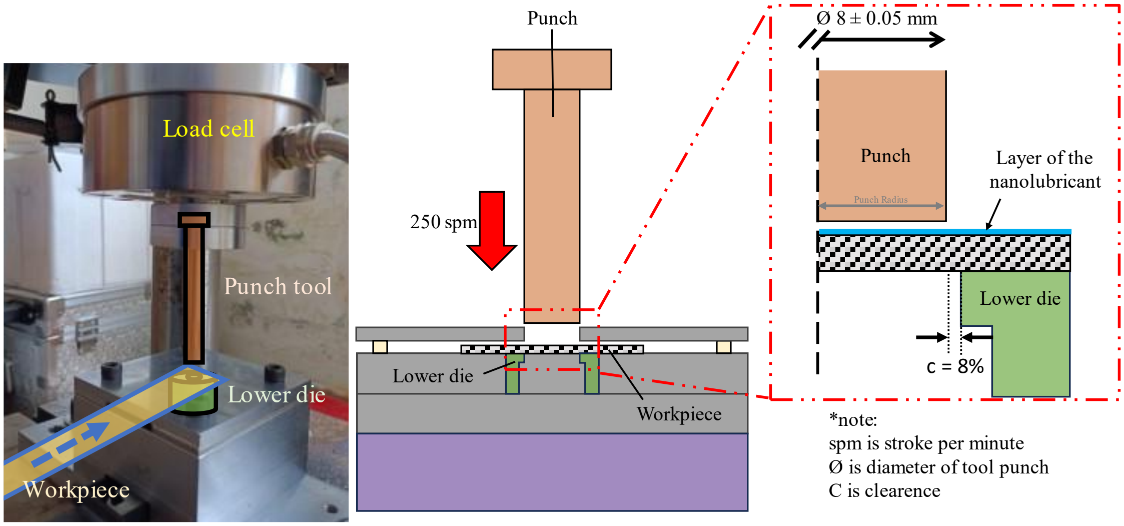
2.4 Viscosity Properties of Formulated Lubricants

Kinematic viscosity is the ratio of absolute viscosity to the density of a fluid (Doğan, 2010), serving to characterize a fluid's resistance to flow in relation to its mass. Formulas of absolute viscosity (Francis & Peters, 1980) used was $\eta = \nu \times \rho$, where η is absolute viscosity, ν is kinematic viscosity, and ρ is density.

The rheological properties of oil-based lubricants were evaluated using an Anton Paar MCR 72 rheometer, according to ASTM D445 standards. Viscosity measurements were performed at a shear rate of 3000 s-1 across the temperature spectrum of 30 °C to 50 °C, using a Peltier plate and cone plate geometry featuring a cone angle of 1° and a diameter of 50 mm.

2.5 Punching and Blanking of Aluminium

A series of punch tests were carried out with 1 mm thick 1060 aluminium sheet and 8 mm diameter tool steel punch. The punching machine has a nominal pressure of 10 kN with a stroke rate of 250 strokes per minute. The punch forward force and the backstroke force were obtained during tests with load cells. During the punching and blanking test, the formulated lubricant was applied to the surface of the aluminium sheet using a brush. An overview of the punching and blanking test setup is shown in Figure 2.



*note:
spm is stroke per minute
Ø is diameter of tool punch
C is clearence

Figure 2: The machine equipped with punching tool, lower and a load cell for measurement of the punch force and the backstroke force and the schematic of punching test.

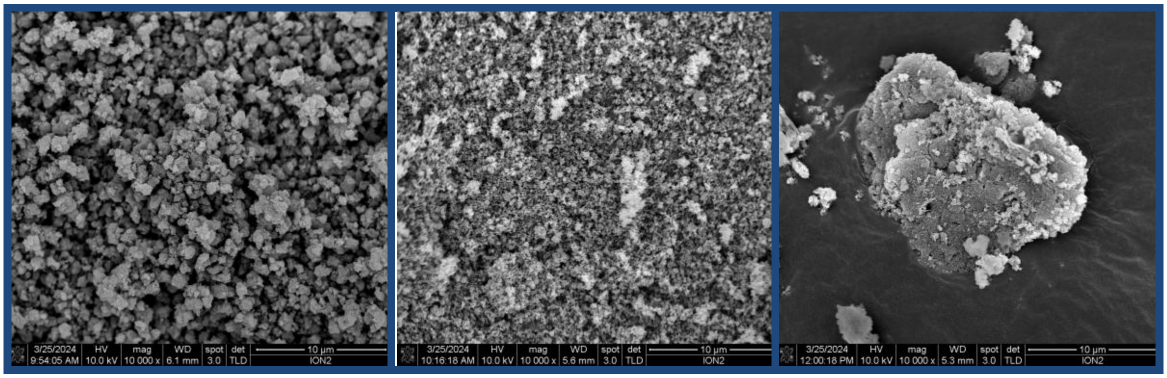
3.0 RESULTS AND DISCUSSION

3.1 Dispersion Stability of Nanoparticle in Oil-Based Lubricant

A sedimentation analysis method was used to measure the stability of formulated lubricant dispersions. The stability of the dispersion was determined by evaluating the amount of sediment and supernatant. After observing the samples, it was found that the MgO, SiC, SiC/MgO, and TiO2 in the formulated lubricants remained stable and homogeneous throughout the 3 days, with no obvious nanoparticle deposition at the bottom. However, a slight and shallow supernatant was observed in the MgO/SiC OBL on Day 3, although it did not increase significantly over time. This small supernatant may be less visible due to the colour of the formulated lubricant itself.

3.2 Nanoparticle Size Analysis

MgO, SiC, and TiO2 nanoparticles in the formulated lubricants exhibit irregular shapes, including hexagonal and nearly spherical shapes as show in Figure 3. The size ranges from about 10 to 40 nm, in line with the specifications provided by the manufacturer. The size and shape of most individual particles can be clearly seen in the Figure 5.



(a) (b) (c)

Figure 3: nano additive of (a) MgO, (b) SiC and (c) TiO2 at 10k magnification.

3.3 Viscosity Properties of Nano-Lubricant

The kinematic viscosity is important, for selecting a suitable oil for any machine (Daniel et al., 2020). The kinematic viscosity is the ratio of absolute viscosity to the density of a fluid. It is used to describe a fluid's resistance to flow in relation to its mass and is important in applications involving fluid motion and diffusion. Equation 1 was used to calculate the kinematic viscosity of nano-lubricant and summarized in Figure 6. All additive samples in the formulated lubricants exhibited higher kinematic viscosities than the mineral oil at room temperature. SiC additive showed the highest viscosity among other additives, with a value of 34.973 mPa.s, followed by TiO2, MgO, and SiC/MgO additives at 34.445 mPa.s, 31.245 mPa.s, and 28.918 mPa.s. From Figure 6, it clearly observed that the viscosity of the formulated lubricant decreasing when the temperature is increasing. As the molecular motion intensifies, the lubricant viscosity decreases, allowing the molecules to move more freely. Consequently, the lubricant experiences reduced resistance to flow, making it less viscous and facilitating smoother flow.

The dynamic viscosity measurement results obtained are shown in the Figure 7. According to viscometer data, the trend observed in all additive lubricants is a decrease in viscosity with increasing temperature. This shows that their rheological behavior follows the same trend at different temperatures. This behavior is consistent with existing literature, which shows that viscosity and particle mobility are inversely proportional to each other, and particle mobility increases with temperature. Comparing the viscosity of all samples, the additives show a higher viscosity than mineral oil. This can be attributed to the inclusion of nanoadditives. Among the nanolubricants, the MgO additive showed the highest dynamic viscosity (20.45 mPa·s @ 30 °C), surpassing the dynamic viscosity of the SiC, MgO/SiC, and TiO2 additives, at 20.04 mPa·s, 19.55 mPa·s, and 19.14 mPa· s, respectively, at 30 °C.

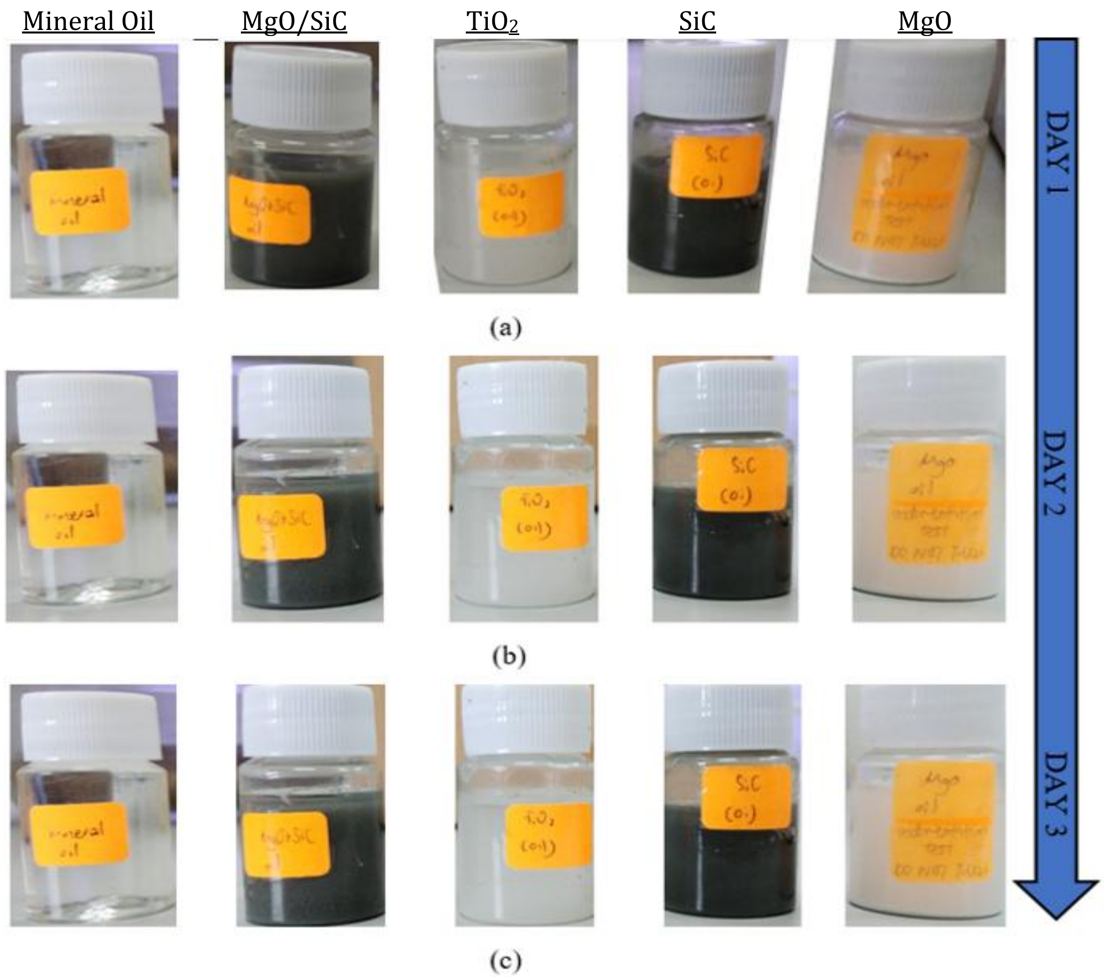
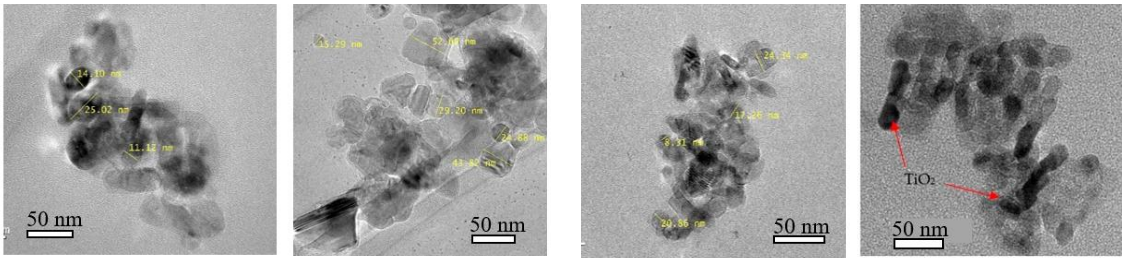


Figure 4: (a-c) Sedimentation test of formulated lubricants from Day 1 to Day 3.



(a) (b) (c) (d)

Figure 5: TEM images of nanolubricants: (a) MgO; (b) SiC;(c) hybrid MgO/SiC; (d) TiO2.

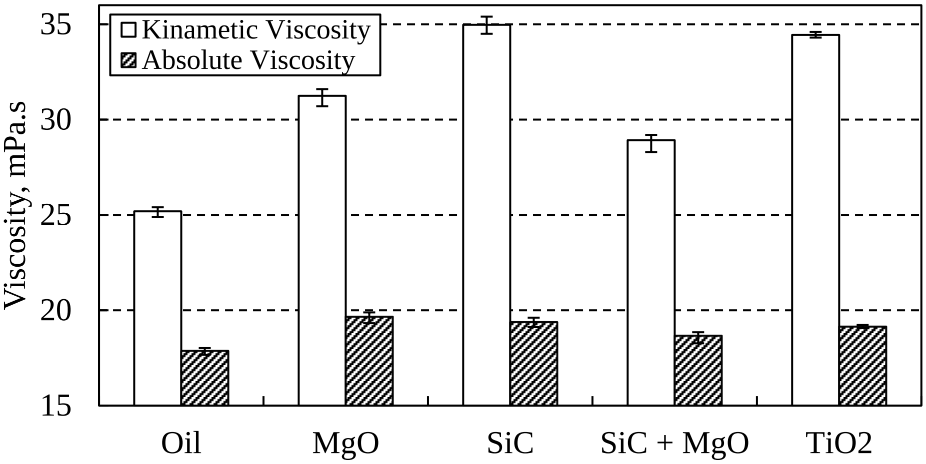


Figure 6: Nanolubricant kinematic viscosity at room temperature for all additives.

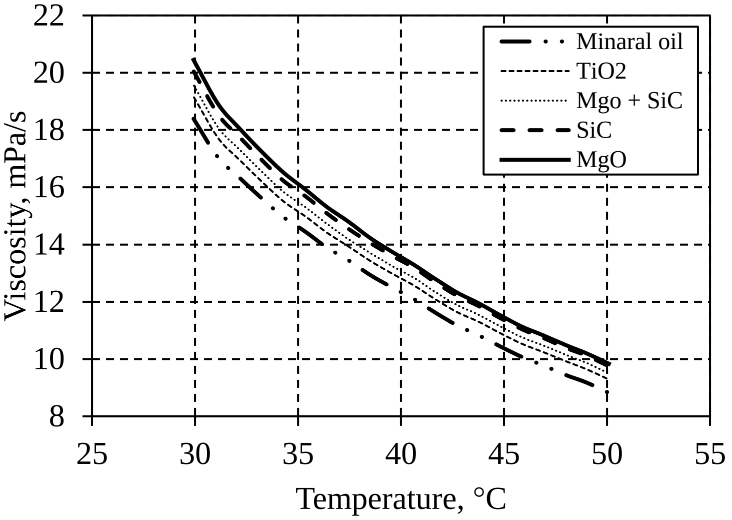
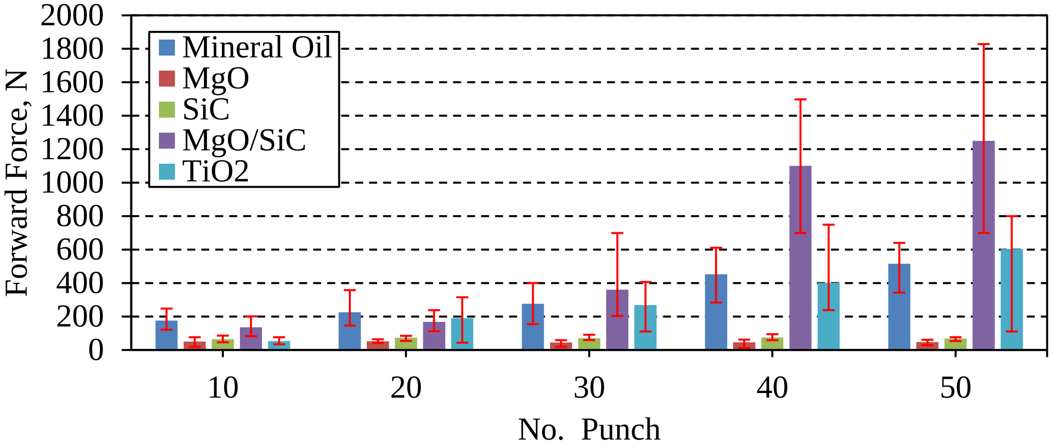


Figure 7: The temperature of the dynamic viscosity of different additive.

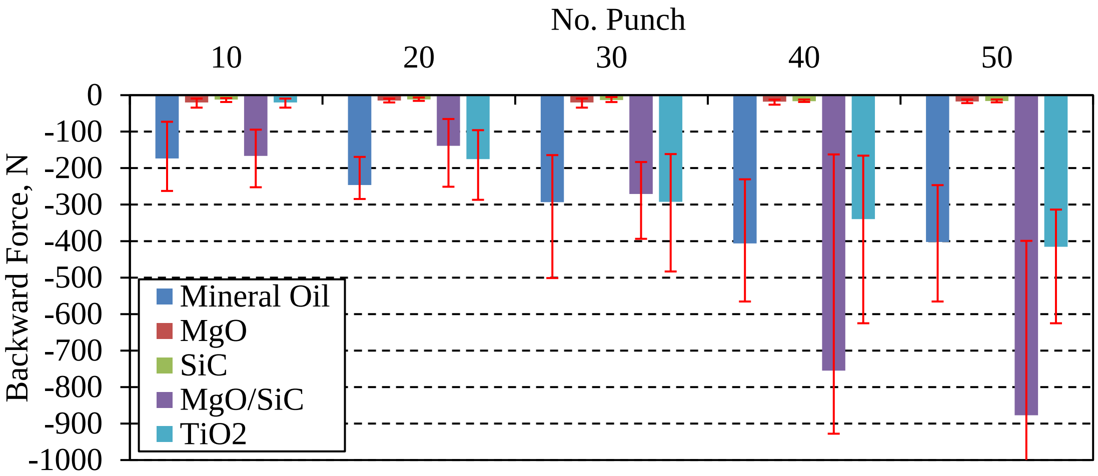
3.4 Punching Force for Different Nanoadditive

The punching and blanking test was conducted with different nanoadditives in the formulated lubricants to evaluate the forward and backward forces applied during punching and retraction of the punch. Figure 8 shows the results of the punching and blanking test for (a) forward and (b) backward forces with various formulated lubricants. The mineral oil was used in the test as the reference. In the first ten punches, the sample with additive exhibits a lower forward force compared to mineral oil at 176 N. This is followed by MgO/SiC, SiC, TiO2, and the lowest forward force is observed with MgO additive. From the 11th to the 20th shot, the forward force for the TiO2 additive increased dramatically to 190 N, surpassing the MgO/SiC additive. From the 21st to the 30th shot, the MgO/SiC additive shows a significant improvement, which is 23% higher than mineral oil and 34% higher than TiO2 additive. The MgO/SiC additive continues to increase with each shot past the 30^{th} shot, reaching up to 1200 N at the 41^{st} to 50^{th} shot. Meanwhile, the forward force of TiO2 additive exceeds that of mineral oil by 17% during the same drilling range. MgO and SiC additive trends remained consistent from the first 10 punches to the 50^{th} punch, with the MgO additive consistently exhibiting the lowest forward force among all samples. In the context of punching, a backward stroke typically refers to a punch that is thrown in a direction opposite to the normal forward punch motion. It is sometimes referred to as a "reverse punch" or a "counterpunch.". The trend for backward force mirrors that of the forward force, with the MgO/SiC additive experiencing a drastic increase after the 31st to 50th punches. However, for the TiO2 additive, the trend is most like that of mineral oil from the 30th to 50th punches. The formation of local weld junctions on the punch stem causes scoring of the workpiece material in subsequent strokes and can introduce large tensile stresses in the punch during the backstroke, which can lead to tool failure (Moghadam et al., 2020).

The MgO additive is the highest viscosity value, due to that, it reduces the wear that develop during the punching or blanking (Moghadam et al., 2020). This is because the smaller particle size of MgO can enhance lubrication efficiency and reduce the risk of particle aggregation. Achieving optimal dispersion of nanoparticles in the lubricant is crucial to maximize their benefits, and the smaller size of MgO facilitates better dispersion. The reduced dimensions of MgO nanoparticles enhance their ability to disperse evenly within the lubricant, minimizing settling or agglomeration. This uniform dispersion ensures that the nanoparticles can effectively interact with lubricated surfaces, providing desired benefits such as improved wear resistance and reduced friction. A protective layer forming on the surface leads to a decrease in surface wear (Singh et al., 2021).



(a)



(b)

Figure 8: (a) forward force and (b) backward force; for the punching test is averaged every 10 shots until it reaches a total of 50 punches.

3.5 Wear Analysis for Aluminium Sample

The image of the workpieces sample with burnish and fracture zone is shown as Table 2. The height is summarized into Figure 10 according to profile in Figure 9. As seen in Figure 10, as the blanking process took place, the specimens showed burnish and fracture zone, influenced by the types of lubricants used. The microscope images in Figure 10 were used to measure the dimensions of burnish, and fracture zones for every ten punches in the aluminium 1060 specimens.

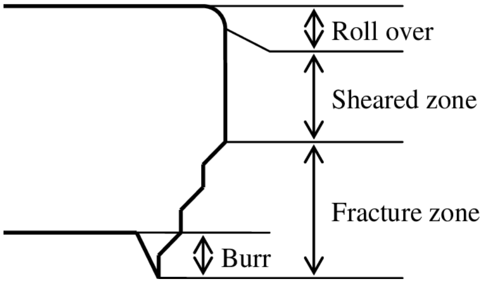
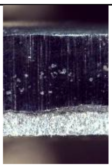
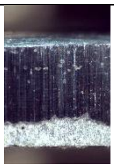
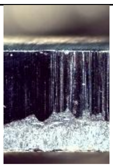
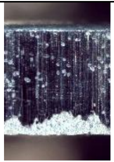
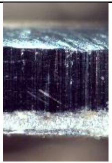
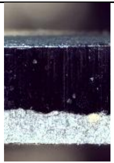


Figure 9: Profile sheared edge scheme (Bohdal et al., 2020).

Table 2: The microscopic image of the cross-sectional burnish and fracture zone of the workpiece.

Test lubricants	**10th Punch**	**20th Punch**	**30th Punch**	**40th punch**	**50th punch**
Mineral Oil					
MgO					
SiC					
TiO2					
MgO/SiC					

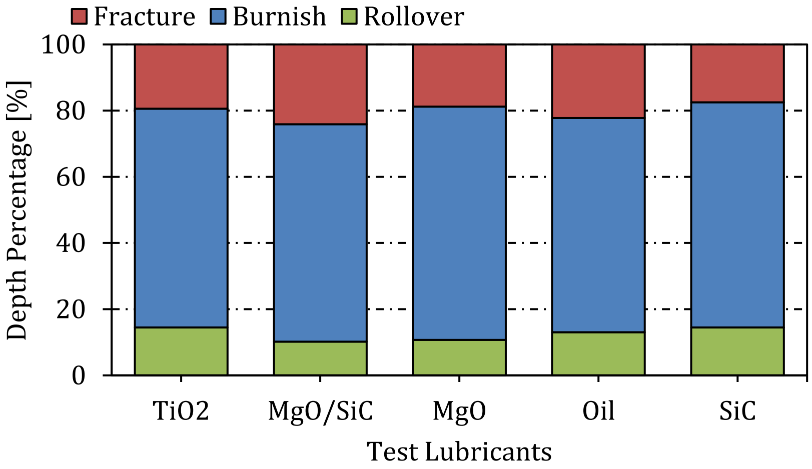


Figure 10: Measurement of cross-sectional burnish and fracture zone of the workpiece.

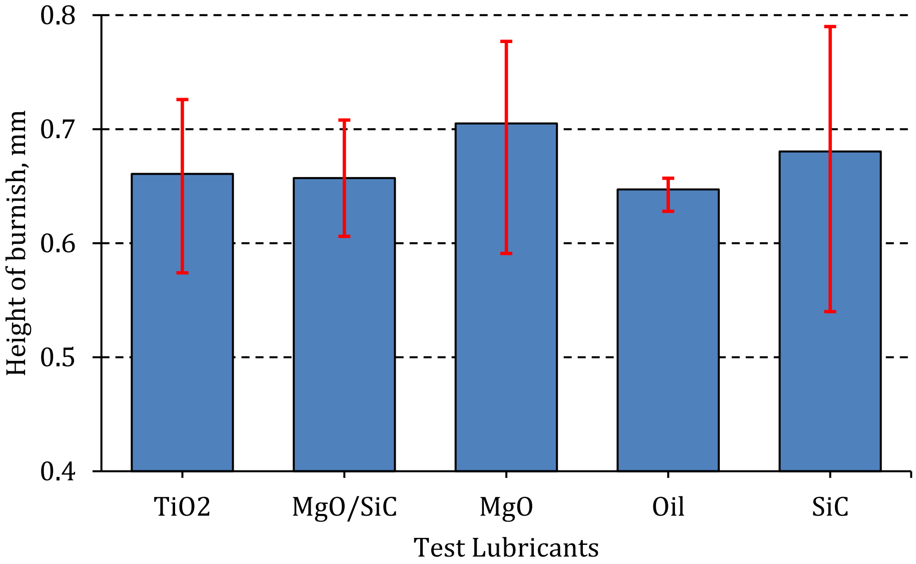


Figure 11: The height of burnish.

Figure 11 shows the average burnish height of slugs after 50 punches of blanking process under the influence of various lubricants: TiO2, MgO/SiC, MgO, oil, and SiC. The burnish height is an important parameter in evaluating the quality of the blanking process, as it directly reflects the smoothness and precision of the cut surface. From Figure 10, it is observed that the MgO lubricant results in the highest burnish height, reaching approximately 0.705 mm. This suggests that MgO provides significant lubrication during the blanking process, leading to a more substantial burnish area, and indicates variability in the results. The lubricants TiO_2 and SiC both result in slightly lower burnish heights than MgO, with values around 0.661 mm to 0.680 mm. TiO_2 and mineral oil result in lower burnish heights, with oil showing the least height at around 0.647 mm, and TiO_2 at approximately 0.657 mm. The reduced burnish height with mineral oil suggests that while it provides adequate lubrication, it does not enhance the smoothness of the cut surface as effectively as the other formulated lubricants. Overall, the results suggest that MgO as the most promising lubricant enhances the burnish height, albeit with some variability. This indicated that the choice of lubricant significantly affects the burnish height, which is critical in applications where surface finish and precision are paramount.

Figure 12 shows the fracture height which is a critical parameter in assessing the quality of the blanking process, as it indicates the extent of material failure during shearing. The lubricant with the highest fracture height is MgO/SiC, indicating a higher degree of material fracture at 0.241 mm during the blanking process when this lubricant is used, followed by oil at 0.222 mm. MgO and SiC show lower fracture heights at 0.188 mm and 0.175 mm, respectively compared to the other lubricants, suggesting that these materials might provide better lubrication, leading to a cleaner cut with less material fracture. TiO2 (0.194 mm) lubricants exhibit moderate fracture heights. SiC, which show lower fracture heights, could be more suitable for processes where a cleaner cut is desired.

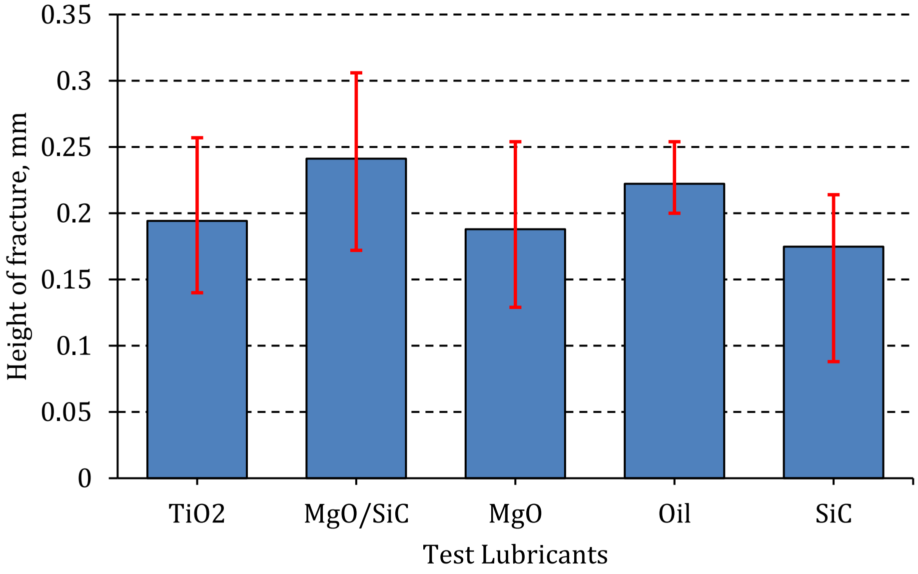


Figure 12: The height of fracture.

CONCLUSIONS

This study assessed the effects of adding nanoadditive in oil-based lubricant on in blanking and punching of aluminium sheets. The following conclusions have been drawn from the findings:

a. The MgO additive can reduce up to 90 % from the mineral oil at 50th shot of punch on the aluminium sheet during the punching operation.
b. MgO and SiC additive can provide less fracture zone when the punch number increase. Less fracture zone on the workpiece is better.

c. The burnish increases as the fracture decreases and only applicable to MgO and SiC nanoadditive.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Malaysia Ministry of Higher Education for the primary financial support under the Fundamental Research Grant Scheme (FRGS/1/2022/TK10/UPM/02/9) for the development and testing of the test lubricants enhanced with nanoparticles. The authors also appreciate the Universiti Putra Malaysia GP-IPM (UPM/GPIPM/2022/9717500) for providing additional financial assistance. Special thanks are extended to the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, for their invaluable assistance and for making their facilities available at every stage of this research.

REFERENCES

Birleanu, C., Pustan, M., Cioaza, M., Molea, A., Popa, F., & Contiu, G. (2022). Effect of TiO2 nanoparticles on the tribological properties of lubricating oil: an experimental investigation. Scientific Reports, 12(1), 5201. https://doi.org/10.1038/s41598-022-09245-2

Bohdal, Ł., Kukiełka, L., Legutko, S., Patyk, R., & Radchenko, A. M. (2020). Modeling and Experimental Analysis of Shear-Slitting of AA6111-T4 Aluminum Alloy Sheet. Materials, 13(14), 3175. https://doi.org/10.3390/ma13143175

Chen, T., Yang, G., Li, Y., Li, Z., Ma, L., Yang, S., & Wang, J. (2022). Temperature-adaptable pressure sensors based on MXene-coated GO hierarchical aerogels with superb detection capability. Carbon, 200, 47–55. https://doi.org/10.1016/j.carbon.2022.08.002

Chen, Y., Renner, P., & Liang, H. (2019). Dispersion of Nanoparticles in Lubricating Oil: A Critical Review. Lubricants, 7(1), 7. https://doi.org/10.3390/lubricants7010007

Choi, S.-B. (2022). Sedimentation Stability of Magnetorheological Fluids: The State of the Art and Challenging Issues. Micromachines, 13(11), 1904. https://doi.org/10.3390/mi13111904

Chouhan, A., Sarkar, T. K., Kumari, S., Vemuluri, S., & Khatri, O. P. (2020). Synergistic lubrication performance by incommensurately stacked ZnO-decorated reduced graphene oxide/MoS2 heterostructure. Journal of Colloid and Interface Science, 580, 730–739. https://doi.org/10.1016/j.jcis.2020.07.033

Dai, W., Kheireddin, B., Gao, H., & Liang, H. (2016). Roles of nanoparticles in oil lubrication. Tribology International, 102, 88–98. https://doi.org/10.1016/j.triboint.2016.05.020

Daniel, J., Žemlička, R., Grossman, J., Lümkemann, A., Tapp, P., Galamand, C., & Fořt, T. (2020). Comparison of Lifetime of the PVD Coatings in Laboratory Dynamic Impact Test and Industrial Fine Blanking Process. Materials, 13(9), 2154. https://doi.org/10.3390/ma13092154

Doğan, S. N. (2010). Rattle and clatter noise in powertrains – automotive transmissions. In Tribology and Dynamics of Engine and Powertrain (pp. 793–838). Elsevier. https://doi.org/10.1533/9781845699932.2.793

Duan, H., Li, W., Kumara, C., Jin, Y., Meyer, H. M., Luo, H., & Qu, J. (2019). Ionic liquids as oil additives for lubricating oxygen-diffusion case-hardened titanium. Tribology International, 136, 342–348. https://doi.org/10.1016/j.triboint.2019.03.069

Francis, W., & Peters, M. C. (1980). Classification, Properties and Units. In Fuels and Fuel Technology (pp. 313–319). Elsevier. https://doi.org/10.1016/B978-0-08-025249-0.50057-4

Gulzar, M., Masjuki, H. H., Kalam, M. A., Varman, M., Zulkifli, N. W. M., Mufti, R. A., & Zahid, R. (2016). Tribological performance of nanoparticles as lubricating oil additives. Journal of Nanoparticle Research, 18(8), 223. https://doi.org/10.1007/s11051-016-3537-4

Hambli, R. (2002). Design of Experiment Based Analysis for Sheet Metal Blanking Processes Optimisation. The International Journal of Advanced Manufacturing Technology, 19(6), 403–410. https://doi.org/10.1007/s001700200041

Hernández, J. J., Franco, P., Estrems, M., & Faura, F. (2006). Modelling and experimental analysis of the effects of tool wear on form errors in stainless steel blanking. Journal of Materials Processing Technology, 180(1–3), 143–150. https://doi.org/10.1016/j.jmatprotec.2006.05.015

Ilyas, S. U., Pendyala, R., & Marneni, N. (2014). Preparation, Sedimentation, and Agglomeration of Nanofluids. Chemical Engineering & Technology, 37(12), 2011–2021. https://doi.org/10.1002/ceat.201400268

Kong, L., Sun, J., & Bao, Y. (2017). Preparation, characterization and tribological mechanism of nanofluids. RSC Advances, 7(21), 12599–12609. https://doi.org/10.1039/C6RA28243A

Lind, L., Peetsalu, P., & Sergejev, F. (2015). Wear of different PVD coatings at industrial fine-blanking field tests. Materials Science, 21(3). https://doi.org/10.5755/j01.ms.21.3.7249

Liu, H., Xie, M., Pan, B., Li, N., Zhang, J., Lu, M., Luo, J., & Wang, H. (2022). In-situ intercalated pyrolytic graphene/serpentine hybrid as an efficient lubricant additive in paraffin oil. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 652, 129929. https://doi.org/10.1016/j.colsurfa.2022.129929

Liu, H., Xie, M., Pan, B., Wang, B., Zhang, L., Zhou, Y., Li, N., Yue, E., & Wang, H. (2023). Boosting the tribological properties of PEG200 by a novel face-to-face FeOCl/Zn-MOF lubricant additive. Journal of Molecular Liquids, 391, 123409. https://doi.org/10.1016/j.molliq.2023.123409

Mahara, M., & Singh, Y. (2020). Tribological analysis of the neem oil during the addition of SiO2 nanoparticles at different loads. Materials Today: Proceedings, 28, 1412–1415. https://doi.org/10.1016/j.matpr.2020.04.813

Moghadam, M., Villa, M., Moreau, P., Dubois, A., Dubar, L., Nielsen, C. V., & Bay, N. (2020). Analysis of lubricant performance in punching and blanking. Tribology International, 141, 105949. https://doi.org/10.1016/j.triboint.2019.105949

Monteil, G., Gréban, F., & Roizard, X. (2008). In situ punch wear measurement in a blanking tool, by means of thin layer activation. Wear, 265(5–6), 626–633. https://doi.org/10.1016/j.wear.2007.12.014

Morshed, A., Wu, H., & Jiang, Z. (2021). A comprehensive review of water-based nanolubricants. In Lubricants (Vol. 9, Issue 9). MDPI. https://doi.org/10.3390/lubricants9090089

Mulyadi, I. H., Issn, |, Sutanto, A., Mulyadi, H., & Vernando, F. (2022). Tool Life in Turning Processes: Effect of Lubricants with a Small Amount of Graphite as Cutting Fluid METAL: JURNAL SISTEM MEKANIK METAL: Jurnal Sistem Mekanik dan Termal Tool Life in Turning Processes: Effect of Lubricants with a Small Amount of Graphite as Cutting Fluid. https://doi.org/10.25077/metal.6.2.69-76.2022

Sergejev, F., Peetsalu, P., Sivitski, A., Saarna, M., & Adoberg, E. (2011). Surface fatigue and wear of PVD coated punches during fine blanking operation. Engineering Failure Analysis, 18(7), 1689–1697. https://doi.org/10.1016/j.engfailanal.2011.02.011

Singh, Y., Badhotiya, G. K., Gwalwanshi, M., Negi, P., & Bist, A. (2021). Magnesium oxide (MgO) as an additive to the neem oil for efficient lubrication. Materials Today: Proceedings, 46, 10478–10481. https://doi.org/10.1016/j.matpr.2020.12.1181

Spikes, H. (2015). Friction Modifier Additives. Tribology Letters, 60(1), 5. https://doi.org/10.1007/s11249-015-0589-z

Wang, K., Wu, H., Wang, H., & Liu, Y. (2020). Superior extreme pressure properties of different layer LDH nanoplatelets used as boundary lubricants. Applied Surface Science, 530, 147203. https://doi.org/10.1016/j.apsusc.2020.147203

Wang, X.-B., & Liu, W.-M. (2013). Nanoparticle-Based Lubricant Additives. In Encyclopedia of Tribology (pp. 2369–2376). Springer US. https://doi.org/10.1007/978-0-387-92897-5_1245

Yu, B., Wang, K., Pang, X., Wu, G., Pu, J., & Zhao, H. (2022). Tribological properties of alkylated reduced graphene oxide as lubricant additive. Tribology International, 165, 107273. https://doi.org/10.1016/j.triboint.2021.107273

Yu, W., & Xie, H. (2012). A Review on Nanofluids: Preparation, Stability Mechanisms, and Applications. Journal of Nanomaterials, 2012, 1–17. https://doi.org/10.1155/2012/435873

Zhou, C., Li, Z., Liu, S., Ma, L., Zhan, T., & Wang, J. (2022). Synthesis of MXene-Based Self-dispersing Additives for Enhanced Tribological Properties. Tribology Letters, 70(2), 63. https://doi.org/10.1007/s11249-022-01605-3

Zhou, C., Li, Z., Liu, S., Zhan, T., Li, W., & Wang, J. (2022). Layered double hydroxides for tribological application: Recent advances and future prospective. Applied Clay Science, 221, 106466. https://doi.org/10.1016/j.clay.2022.106466