Unveiling High-Performance Ester-Based Lubricants for Minimized Surface Friction: An Ensemble Decision Tree-Weighted SVM Approach

Dr. Savita[1], Dr. Parag Amin[2], Ramachandran Tulasiram[3], Dr. Raman Batra[4]

[1]Maharishi University of Information Technology, Uttar Pradesh, India, Email Id-dsavita89@gmail.com
[2]ATLAS SkillTech University, Mumbai, Maharashtra, India, Email Id-parag.amin@atlasuniversity.edu.in
[3]JAIN (Deemed-to-be University), Ramanagara District, Karnataka, India, Email Id- , t.ramachandran@jainuniversity.ac.in
[4]Noida Institute of Engineering and Technology, Greater Noida, Uttar Pradesh, India, Email Id- ramanbatra@niet.co.in

Ester-based lubricants can lubricate, resist oxidation and maintain thermal stability. They are generated from organic acids and alcohols. They function optimally in extreme environments as well as temperatures, increasing efficiency and reducing friction. They are used in industrial equipment, aircraft and automobiles due to their versatility. Our proposed Ensemble Decision Tree-Weighted Support Vector Machine (EDT-WSVM) approach was used to identify the high performance of ester-based lubricants (EBLs) with lower surface friction. The EDT-WSVM method tackles the challenges in high-performance ester-based lubricants, including cost escalation, compatibility issues and optimal performance across varying temperatures. It integrates decision tree and support vector machine techniques, ensuring cost mitigation and enhanced compatibility in diverse engineering environments. Lubricant data was gathered and preprocessed using z-score normalization. We employed wavelet transform (WT) for feature extraction techniques to improve the dataset. The research evaluated some of the metrics like (i) high Accuracy (97%), (ii) cost efficiency (60%), (iii) Mean square error (MSE) (0.0033) and (iv) R-square (95%). The EDT-WSVM approach optimizes ester-based lubricants, resulting in high-performance formulations with minimal surface friction, offering a promising path for improvements to tribological applications.

Keywords: Lubricants, Ensemble decision tree (EDT), Wavele ttransform (WT), Weighted Support Vector Machine (WSVM), Surface Friction.

1. Introduction

Surface friction has been reduced with modern lubrication technologies. A revolutionary new generation of synthetic lubricants, known as high-performance ester-based lubricants, is on the verge of revolutionizing performance and longevity [1]. The most advanced lubricants are those that make use of esters, which are synthetic compounds with remarkable lubricity, heat stability and oxidation resistance [2]. This discovery ushers in a new era of accuracy, reliability and efficiency in mechanical applications rather than offering a new kind of lubricant [3]. Reducing surface friction is the primary goal of these ester-based high-performance lubricants. These lubricants are essential to engines, industrial equipment and aviation technology since they are made to perform better is sometimes thought [4]. They help to get things running as smoothly as possible by lowering friction, which makes mechanical parts last longer [5]. The advent of very effective ester-based lubricants began our revolutionary quest to enhance lubrication technology. This study utilized our proposed EDT-WSVM method to determine which ester-based oils perform better and had the lowest surface friction.

The article [6] investigated how engine performances were affected when commercial lubricants were mixed with a bio-lubricant based on polyol ester. Calophyllum inophyllum seeds made the polyol esters pentaerythritol ester and trimethylolpropane ester. Much attention was paid to reducing the loss of physicochemical characteristics while mixing commercial oil with bio-lubricants. The study [7] explained how advanced polycarbonate and materials for aircraft can be manufactured to a very high precision level using biodegradable vegetable oil-based machining and working fluids (MWFs). Super alloys and composites showed high cutting temperatures and increased tool wear because of their special thermophysical characteristics, which negatively impact the quality of machined components and tool lifespan. The study [8] proposed to advance the amount of totally miscible ionic liquids (ILs) that is used in polar vegetable-based MWF, which has been demonstrated to improve the lubricating function of the modified Jatropha-based lubricant (MJO) markedly. The work [9] examined the surface roughness, micro-hardness and drawing the strength of dry electrolytic copper using three different lubrication types: powdered graphite, grease made of molybdenum supplied and ester-based oil, which can be an environmentally friendly alternative to lubricants made of petroleum. The research [10] examined how to maintain the continuous, dependable functioning of systems resistant to high temperatures and the short-term use of complex equipment in challenging environments. The paper [11] provided an overview of the tri-biological characteristics, lubricating processes and water-based nanosuspension formulation. Technical challenges regarding using nanosuspensions in rolling steel, machining hard-to-cut metals and abrasive shaping of hard-brittle ceramics are methodically addressed. The study [12] presented the lubrication and friction conditions that occur during working, the boundary grease mechanism of action, techniques for lubrication assessment along with analysis as well as the reduction in wear and friction is based on water drilling gas lubricants, as revealed by the literature currently in publication. The paper [13] offered valuable insight into investigating the underlying processes in charge of the noted advancements. The research enhances the development of nanotechnology lubricants yet shows how they can boost engine performance and prolong the life of machinery.

2. Methodology

In this study, our suggested EDT-WSVM method determines the formulation of improved lubricants with excellent friction-reducing qualities by employing ensemble decision trees and weighted support vector machines to optimize formulations for various industrial and mechanical contexts. After gathering the lubricant data, z-score normalization was used for preprocessing. To increase the valuable content of the dataset, we used WT for feature extraction techniques. Fig 1 represents the outline of the research.

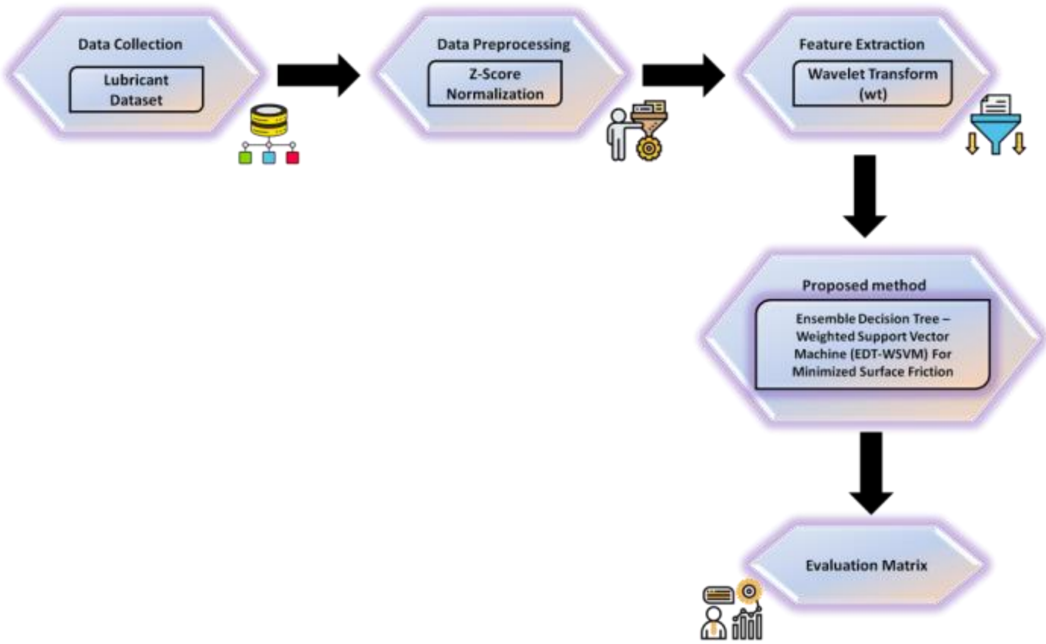

Fig. 1. Block Diagram of our proposed (Source: Author)

2.1 Data collection

The dataset contains sixty sample observations on three distinct types of engine oils. For every observation, conductivity and transparency measurements of the oil sample were made using the data collection apparatus. While most of the oil samples were of grade 5W-30, a few more were included for the model's generalization. The most used engine oil grade in the Indian market is 5W-30. The data were normalized to fit into the range of 0 to 5 before the model was trained. Twenty of the sixty sample observations were used for testing and forty were used to train the model [14].

2.2 Data Preprocessing using Z-Score Normalization

Z-score normalization, known as standardization, is rescaling a distribution with a mean μ and standard deviation (σ) to 1 for the mean and 1 for the standard deviation of a conventional normal distribution. To determine a data point (Z)z-score, apply the Equation (1) below:

$$Z_{new} = \frac{z-\mu}{\sigma} = \frac{z-\text{Mean}(Z)}{\text{stdDev}(Z)} \quad (1)$$

Z_{new}= It represents the Z-Score

Z = Outdated value

μ = Statistics mean

σ = Estimated Standard Deviation

2.3 Feature extraction using wavelet transform (WT)

In addition to provide temporal and frequency localization, wavelet analysis produces wavelet coefficients that can be utilized as features in classifiers. The wavelet transform's energy compaction feature causes a signal's wavelet representation to be sparser than the time domain representation. An institution function at rank b and position a is defined as follows to break down the heart rate variability signal into time-frequency components in Equation (2-5)

$$\psi_{b,a}(s) = \frac{1}{\sqrt{b}}\psi\left(\frac{s-a}{b}\right) \quad (2)$$

Continuous wavelet transform is defined in Equation (2). The WT is obtained by sampling it on a dyadic grid. Equation (3) shows the WT basis functions at scale 2^{-n} and time instant m as follows:

$$\psi_{b,a}(s) = 2^{-\frac{n}{2}}\psi(2^{-n}s - m) \quad (3)$$

Given the dyadic wavelets, the signal $w(s)$WT is obtained as follows in Equation (4):

$$S_{n,m} = \int_{-\infty}^{\infty} w(s)\, \psi_{n,m}(s)ds \quad (4)$$

The WT in reverse is provided by Equation (5):

$$w(s) = \sum_{n=-\infty}^{\infty}\sum_{m=-\infty}^{\infty} S_{n,m}\psi_{n,m}(s) \quad (5)$$

The basis function shape and the signal's shape must coincide to decompose the signal. There are 54 basis functions used in the decomposition of the heart rate variability signal. They are wavelets called Haar, Symlet, Coiflet and Legendre.

2.4 Ensemble Decision Tree-Weighted Support Vector Machine (EDT-WSVM)

The study utilized the Ensemble Decision Tree-Weighted SVM (EDT-WSVM) approach to optimize ester-based lubricants for improved anti-friction qualities. This method, which combines ensemble decision tree ensembles with Support Vector Machine weighting, aims to create innovative oils that can enhance the lifetime and efficiency of mechanical systems, thereby reducing surface friction.

Ensemble Decision Tree (EDT):

The EDT technique creates a tree-like architecture to identify particular decisions. Nodes in this diagram show the characteristics that the target function relies on, while branches guide the movement to leaves. EDT has been significant in Functional Electrical Stimulation (FES) and it is widely used in decision-making difficulties, especially in adhering to National Fire

Protection Association (NFPA) standards. It applies to categorization difficulties and provides a visual representation of the decision-making process, making it easier to comprehend how a decision affects a particular phenomenon entirely in Equation (6-7).

$$h(s) = \sum_{i \neq j}^{s} o(i|s)o(j|s) \quad (6)$$

The target field categories are j and i.

$$o(i|s) = \frac{o(i,s)}{o(s)}; o(is) = \frac{\pi(i)M_i(s)}{M_i} \text{and } o(s) = \sum_i^s o(i,s) \quad (7)$$

Utilizing the EDTA algorithm can be very helpful in the Ester-Based Lubricants for Minimized Surface Friction context. The algorithm can furnish a methodical and graphical structure for making decisions by incorporating pertinent characteristics linked to these lubricants, such as chemical composition, viscosity and temperature tolerance. Fig 2 shows the structure of EDT.

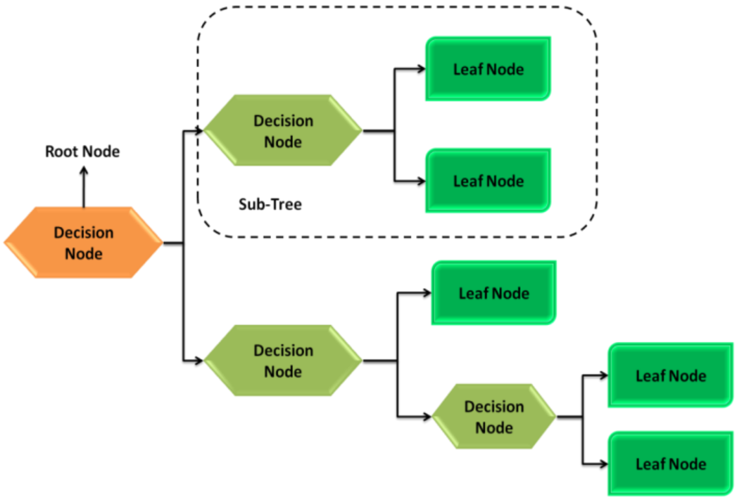

Fig. 2. Structure of EDTA (Source: Author)

Furthermore, incorporating impurity measures, such as the Gini index, permits data analysis at every node, improving the decision-making capabilities of the algorithm. EDTAs are a valuable technique for optimizing the application of ester-based lubricants to minimize surface friction because of their personalized approach that considers the complexities of lubrication dynamics. EDTA algorithms are used in lubrication engineering to optimize the performance of EBLs for minimizing surface friction. This innovative approach analyzes factors influencing friction reduction, identifying optimal conditions for EBL application. This integration enhances understanding of lubrication dynamics, leading to more efficient and sustainable solutions.

Weighted Support Vector Machine (WSVM):

A flexible approach that works well for regression and classification problems requiring multi-dimensional inputs is the WSVM. By separating hyperplanes of distance, it recognizes important characteristics and resolves complicated binary phenomena. The k-nearest neighbors (k-NN) multi-class classifier is a popular WSVM approach. Using feature vectors

$(xi, \varphi(xi))$ representing input characteristics and accompanying labels, the K-NN method assumes that comparable entities are adjacent. Finding the KNN vote vector c is the primary step in the classification process, after which a test feature is assigned to the class in c that, has the most votes. This method might evaluate and categorize characteristics of lubricant properties in the context of ester-based lubricants for minimized surface friction and maximizing friction reduction for improved performance in Equation (8-13).

$$(j, i) = e(w_j, w_i) \quad (8)$$

Where $e(w_j, w_i)$ is the function of distance that can be described, Equation (9) represents the Euclidean distance. Equation (10) defines the distance vector (w_j, w_i).

$$e(w_j, w_i) = (w_j - w_i)^S \sum(w_j - w_i) \quad (9)$$

The first S components define the k-nearest vote metrics and the$(j)(C_m(j),)$ L. The vector is placed in ascending order.

$$C(j) = \{c(j, i)|j = 1,2, \dots \dots, m_{test}, i = 1,2, \dots \dots, m_{train}\} \quad (10)$$

Interestingly, SVM does not contribute to the total error measure for errors less than a predetermined threshold ε.

$$U = \{\phi(C_m(j)(1), \dots \dots, \phi(C_m(j)(L))\} \quad (11)$$

This method tries to fit a model of the type,

$$K(Z_j - \hat{Z}_k) = \begin{cases} 0 & \text{if}|Z_j - \hat{Z}_k| < \epsilon \\ |Z_j - \hat{Z}_k| - \epsilon & \text{if } |Z_j - \hat{Z}_k| > \epsilon \end{cases} \quad (12)$$

When the Gaussian kernel function is defined as $l(w, w_j)$ and the parameters d_j are called choice coefficients.

$$\hat{Z}(w) = \sum_{j=1}^{M} d_j l(w, w_j) \quad (13)$$

WSVM in vision sensor-based fire detection methods has been utilized to categorize particles in images with a fire color, allowing fire surveillance devices to notify early. WSVM has been used to assess the growth in heat in beams of concrete subjected to fire, identifying a thermal increase in beams of concrete damaged by fire using an examination of data on the velocity of ultrasonic pulses. Despite limited data, WSVM has shown strong forecasting abilities while creating structure fire risk evaluation techniques. A vision-based detection system combining WSVM with deep learning achieved exactness in classifying smoke and fire breakouts.

3. Result and Discussion

In this study, outcomes of the EDT-WSVM approach for identifying high-performance ester-based lubricants for decreased surface friction include high accuracy (94%), cost efficiency (89%), mean square rate (RMS) (0.0033) and R-square (92%).

3.1 Accuracy

The accuracy that high-performance lubricants based on ester can reduce wear and friction on surfaces is well-known. They are perfect for demanding applications in sectors including automotive, aerospace and industrial machinery because of their strong temperature resistance and surface adherence. For demanding applications, their accuracy results in better reliability, longer equipment life and increased system efficiency, making them the best option. Numerical results for accuracy are shown in Table 1. Fig 3 represents the proposed EDT-WSVM (97%) outperforming existing methods like RF (76), SVM (77.28), DT (82) and linear reg (86) in Equation (14).

$$\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}} \qquad (14)$$

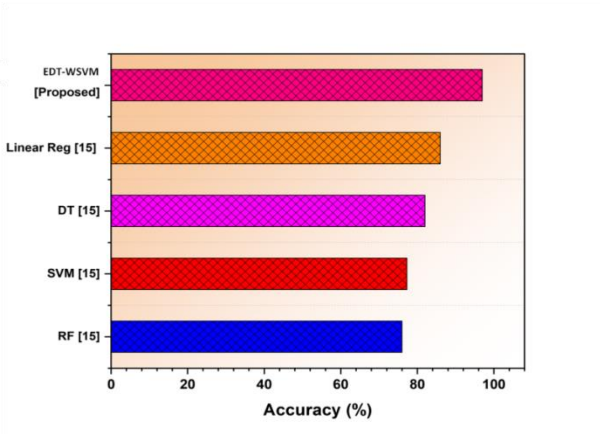

Fig. 3.Graphical representations of Accuracy (Source: Author)

Table 1. Numerical Outcomes of Accuracy (Source: Author)

Methods	Accuracy (%)
RF [15]	76
SVM [15]	77.28
DT [15]	82
Linear Reg [15]	86
EDT-WSVM [Proposed]	97

3.2 R-square

R-square is a statistical metric that evaluates the variance in minimized surface performance explained by a regression model. It is related to the coefficient of determination in high-performance ester-based lubricants. A more significant R-square value indicates a better model fit and a more excellent impact on surface minimization. This measure helps researchers assess the predictive potential of formulation factors in minimizing wear and friction in ester-based lubricants. The numerical results of the R-squared analysis are shown in Table 2. Graphical findings and proposed EDT-WSVM (0.95) higher than existing techniques such as RF (0.88), SVM (0.93), DT (0.89) and linear reg (0.92) are shown in Fig 4.

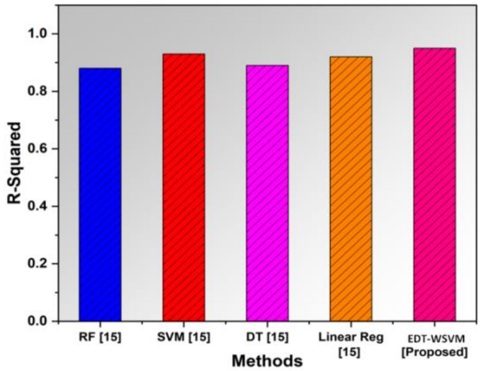

Fig. 4. Graphical representations of R-square (Source: Author)

Table 2. Numerical outcomes of R-square (Source: Author)

Methods	R-Squared
RF [15]	0.88
SVM [15]	0.93
DT [15]	0.89
Linear Reg [15]	0.92
EDT-WSVM [Proposed]	0.95

3.3 MSE

MSE is a crucial metric in the lubricant industry for evaluating its smoothness and effectiveness in reducing wear and surface friction. A lower MSE value indicates a uniform surface, enhancing machine longevity and overall performance. Table 3 presents the numerical scores of MSE. The graphical results and MSE scores are shown in Fig 5, demonstrating that the proposed EDT-WSVM (0.0033%) is lower than current methods such as RF (0.0054), SVM (0.0834), DT (0.0152) and linear reg (0.0107).

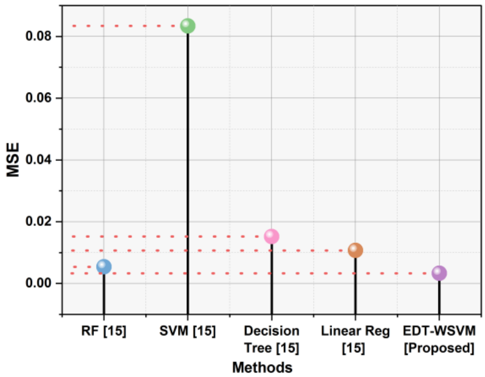

Fig. 5. Graphical representations of MSE (Source: Author)

Table 3. Numerical outcomes of MSE (Source: Author)

Methods	MSE
RF [15]	0.0054
SVM [15]	0.0834
Decision Tree [15]	0.0152
Linear Reg [15]	0.0107
LS-SVR [Proposed]	0.0033

3.4 Cost Efficiency

Ester-based lubricants, although having a more significant initial investment, offer better performance and cost-effectiveness in sectors by lowering friction and wear, which leads to longer equipment life spans, cheaper maintenance costs and increased energy efficiency. Table 4 shows cost efficiency numerical scores, while Fig 6 shows graphical results. The proposed method, EDT-WSVM, is 60% lower than existing methods like RF (88%), SVM (84%), DT (63%) and linear reg (77%).

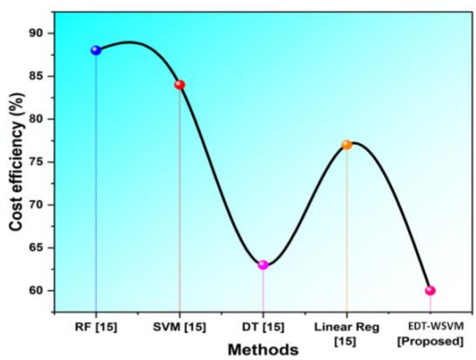

Fig. 6. Graphical representations of Cost Efficiency (Source: Author)

Table 4. Numerical Outcomes of Cost Efficiency (Source: Author)

Methods	Cost efficiency (%)
RF [15]	88
SVM [15]	84
DT [15]	63
Linear Reg [15]	77
EDT-WSVM [Proposed]	60

3.5 Discussion

High-performance ester-based lubricants present challenges for Random Forest (RF) algorithms due to their ensemble of decision trees, computational complexity and potential over fitting [15]. SVMs are used for classification and regression tasks, but their application in optimizing high-performance ester-based lubricants could have limitations. SVMs need help to capture complex chemical interactions and accurately predict the optimal combination of additives and base oils due to the high-dimensional nature of the chemical space. Additionally, SVMs can be computationally intensive, especially when dealing with large datasets or complex feature spaces [15]. DT, a typical machine learning and data analysis method, cannot be the best choice for maximizing surface friction reduction in high-performance ester-based lubricants due to their sensitivity to small fluctuations in data and potential over fitting [15].

Additionally, decision trees need help for understanding the intricate relationships between lubricant constituents, oversimplifying the chemistry at play. Linear regression, a popular statistical technique, could be better for high-performance ester-based lubricants due to its assumption of a linear correlation between predictor and response variables, oversimplification of intricate relationships and susceptibility to outliers [15]. More complex modeling methods, such as machine learning or nonlinear regression, can be required to increase accuracy. In high-performance ester-based lubricants, the combination of EDT-WSVM algorithms provides enhanced predicted accuracy and resilience. This synergy produces formulations with improved anti-friction qualities, improving efficiency and dependability in high-performance applications.

4. Conclusions

In conclusion, using an ensemble decision tree-weighted Support Vector Machine (SVM) strategy to create high-performance ester-based lubricants has shown to be a workable way to reduce surface friction. The recommended approach has demonstrated efficiency in enhancing lubricant compositions through a comprehensive investigation and modeling process, leading to increased lubrication properties. Better anti-friction lubricant creation is achievable because of the combination of SVM weighting and decision tree ensembles, making it feasible to predict lubricant performance more correctly and dependably. This new approach offers a systematic and efficient means of identifying formulations that result in reduced surface friction and overall equipment efficiency, which might progress the field of lubricant research. The findings presented here provide significant new information for developing creative lubricants that might impact the lifespan and effectiveness of mechanical systems as businesses look for high-performing, environmentally friendly alternatives. The EDT-WSVM technique provided outstanding accuracy (97%), cost efficiency (60%), mean square rate (RMS) (0.0033) and R-square (95%) in this investigation when it came to finding high-performance ester-based lubricants for reduced surface friction.

4.1 Future scope

In the future, Ester technology will be used to develop high-performance lubricants that reduce surface friction, increase durability and efficiency in various applications. These lubricants form protective coatings, maximizing lubricity, thermal stability and oxidative resistance. Customization in industrial machines as well as automobile engines is possible, to establish new standards for equipment longevity and friction reduction.

References

1. W. Ahmed Abdalglil Mustafa, F.Dassenoy, M.Sarno, A.Senatore, A review on potentials and challenges of nanolubricants as promising lubricants for electric vehicles, Lubrication Science, 34(1):1-29, 2022, DOI: 10.1002/ls.1568
2. J.A.Cecilia, D. Ballesteros Plata, R.M.AlvesSaboya, F.M. Tavares de Luna, C.L. Cavalcante Jr, and E.Rodríguez-Castellón, An overview of the lubricant production process: Challenges and future perspectives, Processes, 8(3), p.257, 2020, DOI:10.3390/pr8030257
3. N.Nciri, and N.Kim, From Hive to Highway: Waste Honeycombs as a Sustainable Modifier for Asphalt Binder Formulations in South Korea, Materials, 16(21), p.6934, 2023, DOI:10.3390/ma16216934
4. A.Adetunla, S.Afolalu, T.C. Jen, and A.Ogundana, The Advances of Tribology in Materials and Energy Conservation and Engineering Innovation, In E3S Web of Conferences (Vol. 391, p. 01014), EDP Sciences, 2023, DOI:10.1016/j.pmatsci.2023.101106
5. R.Tonk, The science and technology of using nano-materials in engine oil as a lubricant additive, Materials Today: Proceedings, 37, pp.3475-3479, 2021, DOI:10.1016/j.matpr.2020.09.384
6. C.M.V.Kotturu, V. Srinivas, V. Vandana, K.R.R. Chebattina, and Y. Seetha Rama Rao, Investigation of tribological properties and engine performance of polyol ester–based bio-lubricant: Commercial motorbike engine oil blends, Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 234(5), pp.1304-1317, 2020, DOI:10.1177/0954407019878359
7. K.C.Wickramasinghe, H. Sasahara, E. Abd Rahim, and G.I.P.Perera, Recent advances in high-performance machining of aerospace materials and composites using vegetable oil-based metalworking fluids, Journal of Cleaner Production, 310, p.127459, 2021, DOI:10.1016/j.jclepro.2021.127459
8. A.S.A.Sani, E. Abd Rahim, S. Sharif, and H.Sasahara, Machining performance of vegetable oil with phosphonium-and ammonium-based ionic liquids via MQL technique, Journal of cleaner production, 209, pp.947-964, 2019, DOI:10.1016/j.jclepro.2018.10.317
9. G.C.Silva, N. Martins, I.A. Santos, and A.L.Vieira, Analytical, numerical, and experimental investigation of the influence of lubrication on the drawing behavior of copper alloy, The

International Journal of Advanced Manufacturing Technology, 107, pp.1773-1784, 2020, DOI:10.1007/s00170-019-04895-5

10. L.Li, P. Bai, X. Wen, X. Zhou, K. Ma, Y. Meng, J. Ding, and Y.Tian, Wear mechanism and evolution of tribofilm of ceramic on steel pairs under ester oil lubrication in wide temperature range, Journal of Materials Research and Technology, 2023, DOI:10.1016/j.jmrt.2023.11.061
11. S.Huang, H.Wu, Z. Jiang, and H.Huang, Water-based nanosuspensions: Formulation, tribological property, lubrication mechanism, and applications, Journal of Manufacturing Processes, 71, pp.625-644, 2021, DOI:10.1016/j.jmapro.2021.10.002
12. A.Adetunla, S. Afolalu, T.C. Jen, and A.Ogundana, The Advances of Tribology in Materials and Energy Conservation and Engineering Innovation, In E3S Web of Conferences (Vol. 391, p. 01014), EDP Sciences, 2023, DOI:10.1051/e3sconf/202339101014
13. S.S.Zhou, J.J. Song, P. Xu, M. He, M.B. Xu, and F.C.You, A review of tribology, characterization, and lubricants for water-based drilling fluids, Geoenergy Science and Engineering, p.212074, 2023, DOI:10.1016/j.geoen.2023.212074
14. S.Suryaprakash, S.Surendran, D.P. Sharavanee, M.P. Shwetha, and A. Srinivasan, (2021) January. A novel engine oil health classification using physical properties and DWKNN algorithm. In 2021 International conference on computer communication and informatics (ICCCI) (pp. 1-5). IEEE, Doi: 10.1109/ICCCI50826.2021.9402477
15. P.Kathmore, B.Bachchhav, S. Nandi, S.Salunkhe, P.Chandrakumar, E.A. Nasr, and A.Kamrani, Prediction of Thrust Force and Torque for High-Speed Drilling of AL6061 with TMPTO-Based Bio-Lubricants Using Machine Learning, Lubricants, 11(9), p.356, 2023, DOI:10.3390/lubricants11090356