lubricants

Article

Triboelectric Performance of Ionic Liquid, Synthetic, and Vegetable Oil-Based Polytetrafluoroethylene (PTFE) Greases

Nur Aisya Affrina Mohamed Ariffin [1], Chiew Tin Lee [2], Arunkumar Thirugnanasambandam [3], King Jye Wong [4] and William Woei Fong Chong [1,5,*]

[1] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM), Johor Bahru 81310, Johor, Malaysia; nuraisyaaffrina@graduate.utm.my
[2] Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan 94300, Sarawak, Malaysia; tlchiew@unimas.my
[3] Centre for Additive Manufacturing, Chennai Institute of Technology, Chennai 600069, Tamilnadu, India; arunkumar.t@citchennai.net
[4] Department of Mechanical, Materials and Manufacturing Engineering, Faculty of Science and Engineering, University of Nottingham Malaysia, Semenyih 43500, Selangor, Malaysia; kingjye.wong@nottingham.edu.my
[5] Automotive Development Centre (ADC), Institute for Vehicle Systems and Engineering (IVeSE), Universiti Teknologi Malaysia (UTM), Johor Bahru 81310, Johor, Malaysia
* Correspondence: william@utm.my

Abstract: Within electrical contacts, poor electrical conductivity of lubricants can lead to triboelectric charging, causing electrostatic currents and thermal effects, which accelerate lubrication failure. This study aimed to address these challenges by producing and testing three greases with different base oils: ionic liquid ([Oley][Oleic]), synthetic oil (PAO4), and vegetable oil-based synthetic ester (trimethylolpropane oleate). Each grease was prepared with polytetrafluoroethylene powder as the thickener. The greases were tested using a custom-made tribometer, integrated with a grounded electrical current system, with friction tests conducted with up to a 2 A electrical current flow at a constant voltage supply of 4.5 V. Under triboelectric friction testing, [Oley][Oleic] grease outperformed a commercial perfluoropolyether grease by 27.7% in friction and 16.3% in wear. This grease also showed better performance than formulated lithium grease with extreme pressure additives. The study demonstrates that greases with low interfacial resistance can retain their lubrication capacity under triboelectric conditions. These results indicate that [Oley][Oleic] grease, with its ionic liquid base oil, offers a promising solution for applications involving electrical contacts. This study highlights the potential of using advanced base oils and thickeners to enhance the performance and sustainability of lubricants in demanding environments.

Keywords: oleic acid; polyalphaolefin (PAO); trimethylolpropane oleate (TMPO); lubrication; friction; triboelectric

check for updates

Citation: Mohamed Ariffin, N.A.A.; Lee, C.T.; Thirugnanasambandam, A.; Wong, K.J.; Chong, W.W.F. Triboelectric Performance of Ionic Liquid, Synthetic, and Vegetable Oil-Based Polytetrafluoroethylene (PTFE) Greases. *Lubricants* **2024**, *12*, 272. https://doi.org/10.3390/lubricants12080272

Received: 3 July 2024
Revised: 22 July 2024
Accepted: 27 July 2024
Published: 30 July 2024

1. Introduction

Greases are widely used in various industries, including automotive, steel, machinery, food, and textiles, due to their ability to reduce friction and wear between moving parts. They are crucial in electrical contacts, minimizing electrical resistance and preventing overheating [1,2]. Electrical contacts are prone to triboelectric charging, where frictional contact between surfaces leads to electrostatic charge accumulation and thermal effects [3,4]. This can deteriorate friction and wear performance, accelerate oxidation, and cause damage through electrostatic discharge. Furthermore, electrical current flow can cause contact electrification, exacerbating these issues by increasing the potential difference between surfaces with different electron affinities [5,6]. To address these challenges, electrically conductive lubricants are often designed with additives, such as metallic fillers and carbon substances, to facilitate current flow through contacts [7].

Greases of a base oil and a thickener flow when shear stress exceeds their yield point. The bonding between the base oil and the thickener is facilitated by mechanical occlusion, capillary forces, and polar attraction [8]. Grease performance is heavily influenced by this interaction [9,10], and the choice of base oil is integral for maintaining viscosity and thermal stability [11,12]. To counteract triboelectric charging, greases in electrical contacts must have sufficient electrical resistance and dielectric strength to prevent high permittivity and current leakage [7]. These properties ensure that the grease manages better the electron transfers between surfaces, maintaining balanced charge distribution and preventing property alterations. Thus, selecting the right grease is vital for the reliability and longevity of electrical systems.

Traditionally, mineral oils have been used as lubricants due to their suitable viscosity and high oxidation stability [5,13]. However, they are non-biodegradable, non-renewable, and prone to evaporation, causing separation from thickeners in greases [1,14]. Synthetic oils, such as polyalphaolefin (PAO), exhibit outstanding oxidative and thermal stability with low volatility [15]. These properties make PAO-based grease compatible with a wide temperature range and stable under shear stress [16]. Even though PAO offers better properties, it remains non-renewable and expensive [17,18].

Given the environmental concerns with traditional oils, research has focused on eco-friendly alternatives. Vegetable oils, having similar hydrocarbon structures to mineral oils [11], offer biodegradability, renewability, low toxicity, and good lubricity [11,19]. Studies on non-edible vegetable oils in greases, such as castor and coconut oil thickened with lithium soap, show superior tribological performance compared to commercial lithium greases [20]. Fatty acids in these oils enhance lubrication properties, and thickeners absorb vegetable oil better than mineral oil, making vegetable oil-based grease a better sealant [21]. However, their low oxidative stability and susceptibility to hydrolysis are significant drawbacks [18]. Chemical modifications, like esterification and transesterification, can improve these properties, but high costs limit their viability [22–24].

Ionic liquids (ILs) are emerging as potential base oils for greases due to their non-flammability, low volatility, biodegradability, high thermal stability, and dispersibility [25–27]. The strong bonds between ion molecules result in good performance under high shear forces [28]. IL-based greases have shown better anti-wear properties and friction reduction than mineral oil-based greases at various temperatures [29,30]. Studies have shown that ILs, such as imidazolium added to polyurea grease, reduce wear by up to 12 times [31]. Lithium salt ILs mixed with a polytetrafluoroethylene (PTFE) thickener exhibit excellent tribological properties under triboelectric conditions, owing to the conductive properties of IL-based greases [7,29,32]. However, selecting the right ILs to avoid corrosion and ensure good tribological performance is challenging [28,33].

In heavy industries, thickeners made from aluminium, calcium, and lithium are used to withstand extreme conditions [8,34], with lithium-based greases dominating the grease industry [35]. However, the demand for electric vehicles (EVs) has created a supply imbalance, as lithium is critical for battery production [5,36]. Polyurea grease is also commonly used in the high-performance automotive industry [37], having better structural strength and yield stress compared to lithium-thickened grease [38]. Recent studies highlight the use of PTFE micro powder as a thickener for its ability to withstand high temperatures and reduce friction and wear [39,40], which is particularly useful in electronic and semiconductor industries [41,42]. Under triboelectric conditions, PTFE is known for its electrical insulation properties, which can help to avoid arcing in electrical contacts [42]. PTFE's high negative triboelectric charge density and strong electron affinity enhance its insulation properties, making it an excellent electron acceptor material [43]. However, base oils can oxidize and decompose under high temperatures, making the selection of both the base oil and the thickener critical for optimal performance, especially in managing triboelectric effects in electrical contacts.

This study addresses the challenges of triboelectric performance in greases by exploring various base oils, including conventional synthetic hydrocarbons, vegetable oil-based