



RECENT TECHNOLOGICAL ADVANCES IN LUBRICANTS AND GREASES USED IN ELECTRIC VEHICLES

Dr Raj Shah and Natalie Ma focus on how improved performance and reliability of EV lubricants and greases can improve driving range and make the integration of EVs more feasible

Electric vehicles (EVs) continue to reshape the automotive landscape.

As concerns for climate change and non-renewable energy increase, the need for the successful integration of EVs becomes more imperative.

The full integration of EVs into the automotive industry is primarily hindered by the lack of charging station availability and limited driving range [1].

Through technology advances to lubricants and greases, EVs can have increased driving range due to less wear, making it more attractive to consumers and crucial to the complete incorporation of EVs.

EVs redefine lubrication requirements, which have been resolved with new technology emerging in the past three to five years.

Advancements to EVs are made to meet four demands. The first is to improve energy efficiency in order to maximise driving range. This therefore increases EV durability and improves driver convenience.

The second demand is to lower friction at e-axes and decrease wear at high rotational speeds.

Because electric motors operate at higher rotational speeds than internal combustion engines (ICE), lubrication regimes must shift towards mixed or elastohydrodynamic conditions where rheology, thickener structure and oil bleed behaviour are critical.

Friction increases heat generation. While wear increases bearing degradation and noise [2].

The third demand is improved electrical conductivity. EV systems are sensitive to stray currents, electrical discharge machining and static charge accumulation in bearings.

Conventional insulating greases cause charge buildup that discharges across rolling contacts leading to pitting, fluting and early bearing failure [3].

The final demand is thermal and oxidation stability under high heat and prolonged operation [4].

Unlike ICE vehicles, there is no frequent lubricant replacement by oil changes. Poor thermal stability leads to viscosity hardening, or lubricant starvation [5].

By addressing these demands through advancements in grease and lubricant technology, EVs can increase their driving range and durability, ultimately solidifying their market presence by competing with ICE vehicles in the automotive market.

EV drivelines experience sustained high speeds and rapid torque transients. This can contribute to cause lubricant degradation and bearing damage.

Additionally, the integration of motors and gear sets into compact e-axes places thermal stress and wear on lubricants, highlighting the necessity of resistance and thermal stability [6].

To directly confront the challenge of the full immersion of EVs, the mechanisms of lubricants and greases must be researched to improve durability and energy efficiency.

Metal oxide nanoparticle-based lubricants

One of the most significant advances in lubricant technology has been the usage of nanoparticle additives. These have been integral in reducing friction and wear.

The tribological study of aluminum oxide (Al₂O₃) nanoparticles coated with oleic acid from del Rio et al. showed evidence of a higher maximum pressure and load carrying capacity on the operating axles [7].

Each of the formulated Al₂O₃ nanolubricants was tested with a rheometer in a ball-on three pins geometry.

The applied force by the rheometer and controlled temperature conditions allows the friction wear to be measured by on each pin.

A different nanolubricant was placed on each pin [Figure 1]. The tribological test results indicated that the coefficient of friction and wear scar width were reduced by more than half with the Al₂O₃ nanoparticles.

Similarly, in another study by del Rio et al. titanium dioxide (TiO₂) nanoparticles had similar results. They showed reduced friction coefficients by 30% and wear reductions by 73%. Their reduction supports promising improvements in wear mechanisms regarding EV e-axes.

In the coming years, more research must be thoroughly

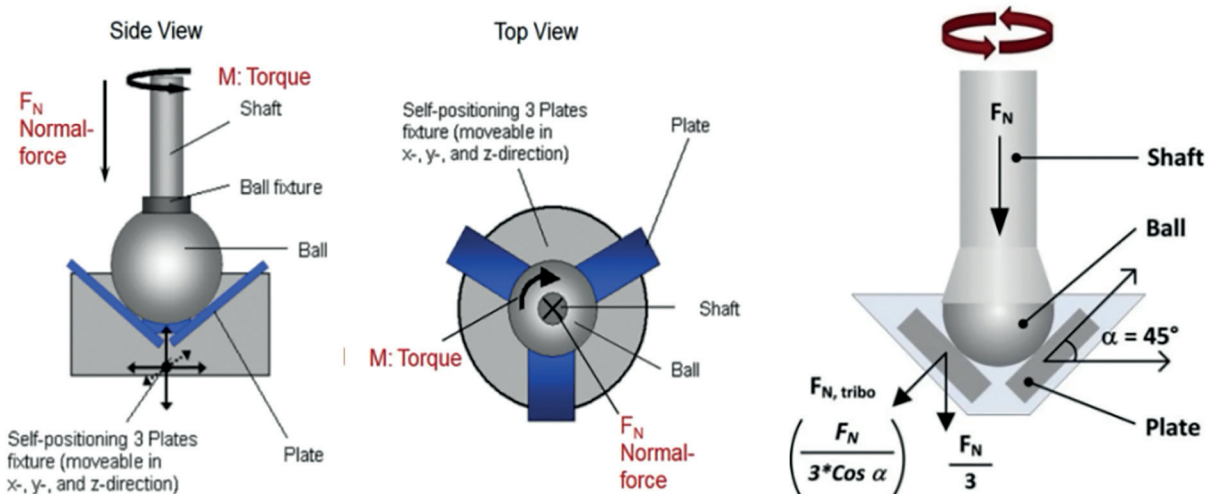


Figure 1: Tribological load test with ball on three plate structure. Applied force by the rheometer measures the frictional wear on each plate. Reproduced from Lauger et al., *New Insights into the Use of a Rotational Rheometer as Tribometer*, 25 (2017), under the CC BY 4.0 license [9]

Roller Number	Test Grease	Timken OK Load (N)	X (mm)	Y (mm)	Wear Scar Area (mm)
a	Base grease (Lithium Grease)	1988	5.3	9.3	154.771
b	1 wt.% rGO	1988	4.7	8.6	126.918
c	2 wt.% rGO	2485	4.7	8	118.064
d	3.5 wt.% rGO	2982	4	7.7	96.712
e	5 wt.% rGO	3976	4.5	7	98.911
f	1 wt.% graphite	1988	5	8.3	130.312

Table 1: rGO additives and grease comparisons. Reproduced from Nassef et al., Impact of Graphene Nano-Additives to Lithium Grease on the Dynamic and Tribological Behavior of Rolling Bearings, 10 (2022), under the CC BY 4.0 license [12].

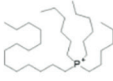
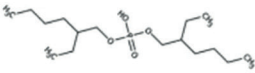
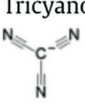
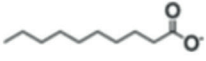
Ionic liquid	Cation	Anion
Trihexyltetradecylphosphonium bis(2-ethylhexyl)phosphate [P _{6,6,6,14}][BEHP] Empirical formula: C ₄₈ H ₁₀₂ O ₄ P ₂ Designation: IL1		Bis(2-ethylhexyl)phosphate 
Trihexyltetradecylphosphonium tricyanomethanide [P _{6,6,6,14}][TCM] Empirical formula: C ₃₆ H ₆₈ N ₃ P Designation: IL2		Tricyanomethanide 
Trihexyltetradecylphosphonium decanoate [P _{6,6,6,14}][DEC] Empirical formula: C ₄₂ H ₈₇ PO ₂ Designation: IL3		Decanoate 

Table 2: Chemical structure and empirical formula of the ionic liquids used in Tuero et al. research. Reproduced from Tuero et al., Phosphonium-based ionic liquids as additives in calcium/lithium greases, 338 (2021), under the CC BY 4.0 license [15].

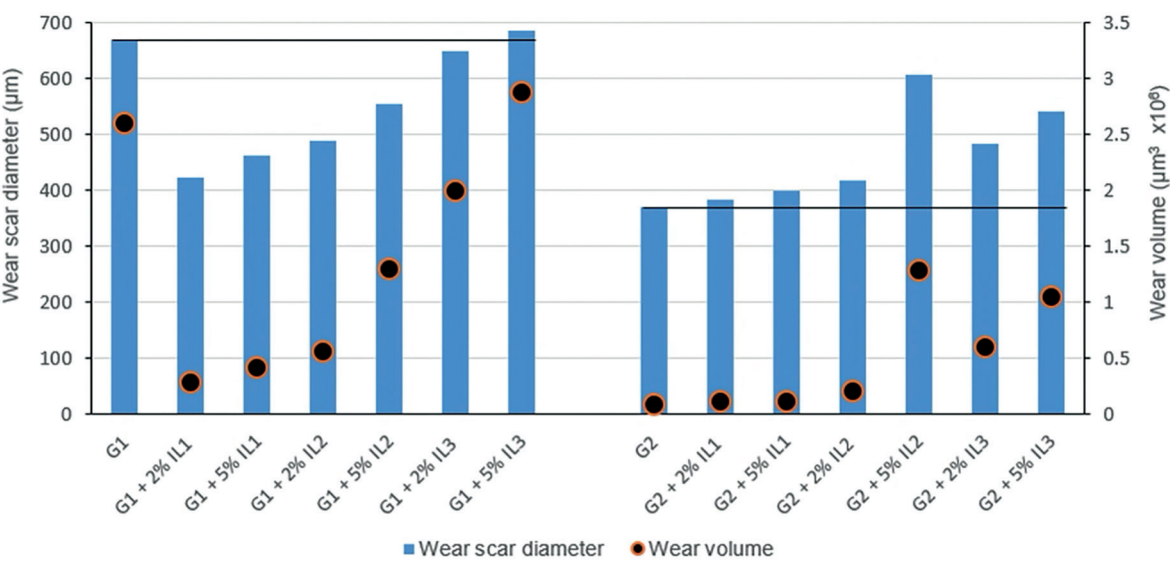


Figure 2: Different ionic liquids additives and their wear scar diameter and wear volume after the 4-balls test. Reproduced from Tuero et al., Phosphonium-based ionic liquids as additives in calcium/lithium greases, 338 (2021), under the CC BY 4.0 license [15].

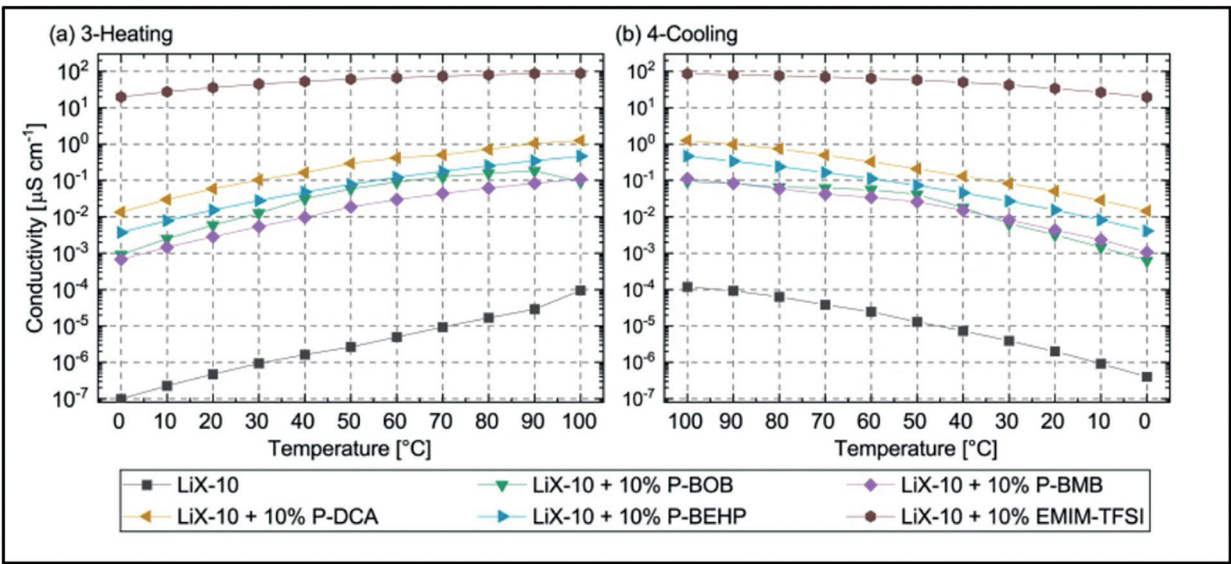


Table 3: Molecular structure and composition of ILs in Reddy et al. study Reproduced from Reddy et al., Colloids and Surfaces A, 683 (2024) 132875, under the CC BY 4.0 license [16]

conducted regarding the incorporation of chemical nanoparticles into lubricants to improve the durability of EVs [8]. Additionally, sustainability-driven research also indicates the development of nanoparticle enriched lubricants derived from palm oil esters. Nugroho et al. reported enhanced wear resistance from 12.99-30% and reduced friction by 12.99-30% when using palm oil-based biolubricants in EV simulations [10]. By combining the use of nanoparticles Al₂O₃ and TiO₂ with palm oil bases, the biolubricants are measurably more sustainable. This lowers both greenhouse gas emissions and energy use. Consequently, the biolubricants not only improve EV efficiency by extending component lifespan but also drive global sustainability. Based on recent studies, the addition of nanoparticle additives to lubricants shows promising potential in enhancing the wear and frictional resistance of lubricants and therefore improving EV functions for longer periods of time.

Reduced graphene oxide-based additives to grease

The addition of carbonaceous nanomaterials including CNTs, graphene and reduced graphene oxide (rGO) to lubricating grease has been suggested to improve lubricant properties including viscosity, layering and enhanced physical or chemical adsorption, in rolling electrical bearings significantly [11]. Naseef et al. researched graphene grease lubricants with different weight percentages of rGO, specifically focusing on its tribological and dynamic behaviour effects on rolling machinery components [12]. Through full bearing tests, vibration modal analysis and standard lubrication tests, carbonaceous additives inducing graphene and others were compared to determine scales of improvement in grease lubricant. Timken load tests were also performed. They revealed the addition of 2 wt.%, 3.5 wt.%, and 5 wt.% rGO additives to commercial lithium grease increased load-carrying capacities by 25%, 50%, and 100% respectively compared to samples of base grease without additives [13]. There were also measurable improvements in wear scar size, reduction in friction forces between contacting surfaces and bearing elements. The addition of 2 wt.%, 3.5 wt.%, and 5 wt.% rGO additives shows beneficial outcomes towards rolling element bearings through increased carrying capacities by over 500 N and decreased wear scar area by over 40 mm [Table 1]. This is significant to EV technology as it contributes to durability in EV bearings through lubricant improvements.

Ionic liquids in electrically conductive lubricants

Conductive lubricants are crucial for EVs. They allow components to avoid premature failure and electromagnetic interference problems [14]. Tuero et al. shows how ionic liquids (IL) can be added to lubricants. This impacts the electrical conductivity and tribological behaviour of automatic transmission fluid (ATF) [15]. Tuero's work focuses on the addition of three ILs with different chemical structures described as IL1, IL2, and IL3 (Table 2). The addition of IL1, with properties of higher thermal stability, subsequently improved the thermal stability of base greases. IL1 and IL2 exhibited increased antiwear behaviour due to phosphorus surface interactions according to Figure 2 from the decreased wear scar diameter. The addition of phosphonium-based ILs as an additive can promote the formation of phosphorus tribofilm which correlates to improved antiwear performance and electrical compatibility.

Cation	Anion	Designation	Source
trihexyl(tetradecyl)phosphonium	bis(oxalato)borate	P-BOB	[65]
	bis(mandelato)borate	P-BMB	[66]
	dicyanamide	P-DCA	Cytec
	bis(2-ethylhexyl)phosphate	P-BEHP	Iolitec
1-Ethyl-3-methylimidazolium	bis(trifluoromethylsulfonyl)imide	EMIM-TFSI	Iolitec

Figure 3: Electrical conductivity of grease samples with ILs dependent on temperature conditions; Heating (a); Cooling (b) Reproduced from Reddy et al., Colloids and Surfaces A, 683 (2024) 132875, under the CC BY 4.0 license [16]

Additionally, Reddy et al.'s work further highlights the versatility of ILs as lubricants [16].

Reddy tested five different IL additives with different chemical compositions including P-BOB, P-BMB, P-DCA, P-BEHP, and EMIM-TFSI [Table 3].

Through conductivity tests with temperature-dependent conditions, the addition of ILs shows evidence of an increased grease conductivity.

The EMIM-TFSI additive resulted in the highest conductivity with results more than three times higher than the conductivity of the P-DCA. In both heating and cooling conditions, the conductivity of the greases is enhanced by additive ILs [Figure 3].

In both studies, the conclusions show improved electrical conductivity with neat ILs highlighting the promise of IL additives.

The addition of ILs are evident as significant technical advancements towards EVs. This is because they provide a more streamlined way to produce conductive lubricants through an additive [17].

Therefore, this process allows EV lubricants to be more conductive, reducing failure and electromagnetic interference.

Layered kaolin additives to lubricants

In recent years, two-dimensional layered nanomaterials are commonly used for solid lubrication [18].

However, there is limited work on the use of two-dimensional layered nanomaterials as lubricant additives.

Zhu et al. introduces how layered Kaolin, an aluminosilicate material, has the potential of acting as an inexpensive lubricant additive with promising results [19].

At the micro and nano layers, the effects of Kaolin additives were tested for various physical and chemical properties [20].

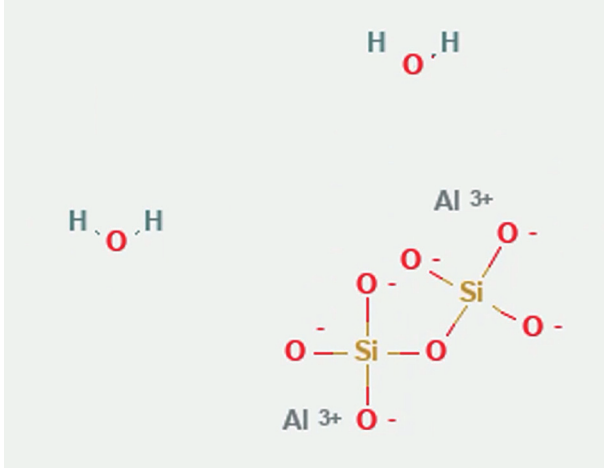


Figure 4: Two-dimensional structure of Kaolin Reproduced from National Center for Biotechnology Information (2026), under the CC BY 4.0 license [20]

Zhu et al. indicates that Kaolin additives tests were performed with light paraffin oil and kaolin oil samples of different particle sizes (from 500 nm to 20 μm) and concentrations (from 0 wt% to 7 wt%).

Through a four-ball friction tester, the most optimal size of kaolin lubricants was at 5 wt% concentration and 2 μm particle size for friction reduction with no modifiers added.

Additive modifiers were also tested for friction and wear diameter effects. The friction coefficient was largest when no modifier was

added but when Span80, CTAB, oleic acid, and stearic acid was added, the friction coefficient decreased by 40.9%, 30.9%, 20.2%, and 26.1% respectively (Figure 5).

Similarly, no added modifiers prove the optimal results in diameters of wear. The wear spot diameters of kaolin oil with Span80, oleic acid, stearic acid, and CTAB decreased by 43.8%, 32.6%, 17.3%, and 4.2% respectively.

In both cases, unmodified layered kaolin oil samples have the best reduction in the coefficient of friction and wear spot diameter.

This improves the lubricating performance as kaolin particles can chemically generate a lubricant film to reduce friction further.

Mohammad et al. also discuss the inexpensive and accessible applications of kaolin [21]. Kaolin requires less intensive extraction and high purity. This makes it highly beneficial for large scale production.

The formulations and availability of kaolin increase its cost-effective value for use across industries including the EV industry.

Ultimately, kaolin's extreme accessibility has promising insight to the EV industry. It facilitates an effective lubricant additive to increase the wear and durability of EVs [22].

Because kaolin is inexpensive, easy to mass produce, and has strong properties of stability, it can change the EV lubricant industry through its high return and profitability.

Microstructures of calcium-sulphonate grease

The development of the Ca-sulphonate grease market has been integral in improving the function of EV vehicles with grease.

Chevron Products Company investigated integrating thicker microstructures on existing Ca-sulphonate complex greases and their consequent effects of physicochemical and tribological properties [23].

Typically, Ca-sulphonate greases are notable for their ability to withstand extreme pressure, antiwear, water resistance and corrosion resistance.

Kumar et al. expanded on the durability and technical advantages of Ca-sulphonate complex greases by utilising a proprietary manufacturing process with mineral base oils and ingredients, different from commercial Ca-sulphonate greases.

Kumar's Ca-sulphonate complex grease was compared to commercial Ca-sulphonate grease through the same series of tests.

The lab-prepared grease (GRS0003276) outperformed the commercial grease (GRS06420). It exhibited higher temperature capabilities, antiwear properties, outstanding extreme pressure, high temperature life and better performance in water and rust protection.

Table 4: Measurement of different morphologies defining microstructure in compared greases

	Needle morphology		Capsule morphology	
	Length (nm)	Width (nm)	Length (nm)	Width (nm)
GRS-06420	23.3±7.6	4.4±1.0	n/a	n/a
GRS-0003276	21.0±8.5	2.5±0.4	16.4±6.4	5.7±1.3

Fundamentally, the characteristics of the functionality and properties of the Ca-sulphonate greases greatly attributed to their microstructure differences.

The full immersion of EVs is challenged by lower driving ranges and high costs. Because of this, the mechanisms of lubricants and greases must be researched to improve durability and energy efficiency

The thickener microstructure, processing and composition led to the lab-prepared greases outperformance of the commercial grease.

The microstructure of the GRS0003267 contained three phases with >80% needle-like and capsule-like morphology.

The additional capsule morphology in GRS0003276 contributes to a superior performance over GRS06240 (Table 4).

The growth of this lab-prepared grease is essential for lithium greases. They are constantly used in the lithium batteries and electronics in electric vehicles.

This is especially important due to recent uncertainty in the supply of lithium [24].

Bio-grease thickeners

Thickeners are commonly used in EV grease to improve thermal stability, lower the coefficient of friction and create longer lifespans of e-motor bearings [2].

Lithium thickeners are most commonly used. However, in 2024, Abouelkasem et al. introduced a bio-grease created from a hybrid vegetable oil and glycerol monostearate [25].

Activated carbon nanoparticles (ACNPs) were also incorporated into the bio-grease. This allows it to serve as a lubricant for roller bearings.

In comparison to commercial lithium grade, they demonstrated significant percentage improvements in friction coefficients and scar diameters.

The bio-grease (CJB1, CJB2) was prepared with base oil, glycerol monostearate and added carbon nanoparticles and was conducted through material characterisation, tribological tests, kinematic viscosity tests and others.

The addition of the bio-grease demonstrated effective properties for withstanding extreme pressure, mitigating friction and wear in rolling bearings.

In a similar study, the mechanisms of glycerol monooleate (GMO) additives were investigated to determine their effects on the properties of lubricants.

Weiwei Wang et al. added 5% weight GMO into base oils and evaluated the friction coefficient and wear.

At both high and low temperature, the added GMO showed a reduced friction coefficient [26]. More specifically, the coefficient of friction decreased the most at lower temperatures (Figure 6).

When temperatures were increased, the wear would increase gradually with temperatures. Yet, the tests show little overall change to the anti-wear performance of the GMO additive.

The exploration of lubricant additives and thickeners reduces the wear in roller bearings and thus allows rotating machinery to have leveraged bearings and gear functions.

By modifying the original lubricant properties, lubricants can increase their durability and resistance to wear, sustaining EV durability [27].

The improvements in lubricants are crucial to EV technology as it allows energy conservation for the rolling electrical bearings.

Conclusion and future outlook

EVs continue to increase in popularity. This is primarily through the tax credit appeal to consumers, opportunities to address climate change and diminish non-renewable energy usage.

The full immersion of EVs is challenged by lower driving ranges and high costs.

Because of this, the mechanisms of lubricants and greases must

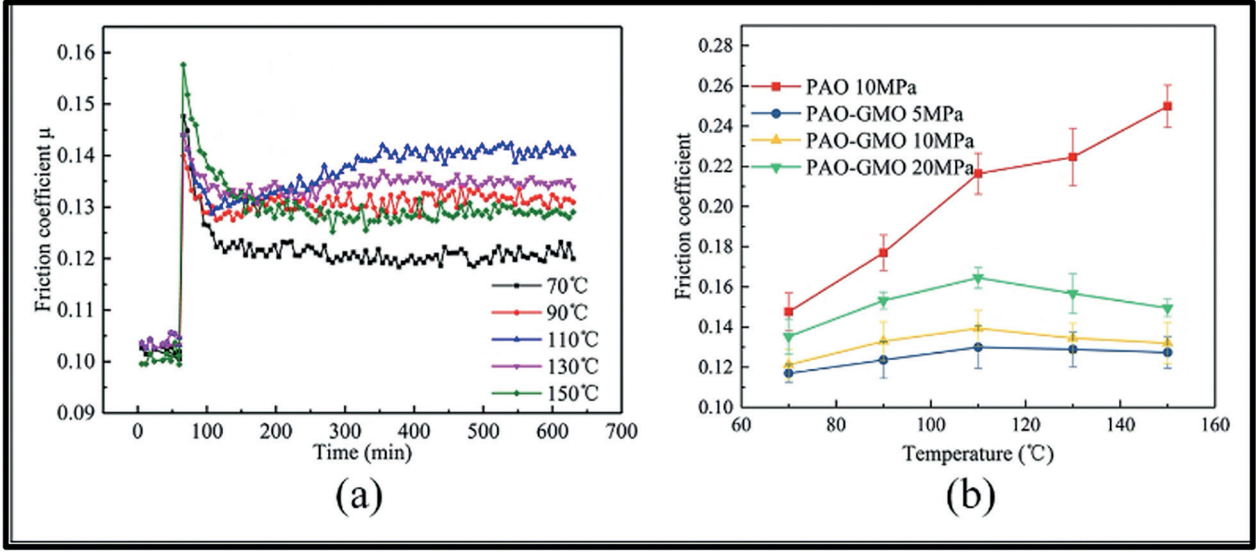


Figure 5: Friction coefficient versus testing temperature (a); stable friction coefficient at different temperature and load (b). Reproduced from Wang et al., Friction reduction mechanism of glycerol monooleate, 104 (2021), under the CC BY 4.0 license [26].

be researched to improve durability and energy efficiency.

The technical advancements of nanoparticles and additives to lubricants and grease have shown promising results to reduce the coefficient of friction and improve the wear resistance in EV mechanisms to optimise energy conservation.

However, more research must be conducted to foresee the total incorporation of these technological advancements into consumer grade EVs.

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