



# Application Note #1024

## Optimizing Lubricant Formulations for EVs: A Comprehensive Tribotesting Approach

The shift toward electric vehicles (EVs) necessitates the development of specialized lubricants tailored to their unique operating conditions. Unlike internal combustion engines, electric drivetrains operate with distinct architectures, posing new challenges in friction and wear management. Electrified tribology testing replicates the electrical and mechanical stresses experienced by EV components, providing crucial insights into lubricant performance under real-world conditions. This application note explores the role of electrified tribotesting in optimizing EV lubricants, focusing on their frictional, wear, and thermal properties. The impact of electrical currents on the friction and wear of lubricated sliding steel contacts is investigated using a pin-on-disc Bruker UMT TriboLab® tribometer setup equipped with AC and DC power sources. Both electrified and unelectrified tribological tests were performed on steel ball-on-flat contacts at varying speeds, loads, and lubricant temperatures with commercially available EV fluids. The findings indicate that the coefficient of friction (COF) and wear are affected by the application of AC and DC currents through the contact.

### Friction and Wear Testing of Electric Vehicle Lubricants

The transition from internal combustion engines (ICE) vehicles to electric vehicles (EVs) represents a transformative shift in the automotive industry, driven by the need to reduce emissions and improve energy efficiency. This shift necessitates the development of specialized lubricants that can meet the unique demands of EV systems. Unlike ICE vehicles, which rely heavily on engine oil for lubrication, EVs primarily require lubricants for their electric drivetrains, gearboxes, and bearings. These components operate under different conditions, posing distinct challenges in terms of friction and wear management. As such, understanding and optimizing the performance of EV lubricants through friction and wear testing is crucial for enhancing the efficiency, durability, and reliability of EVs.

Friction and wear testing of EV lubricants involves evaluating their ability to minimize frictional resistance and material degradation under various operating conditions. Unlike conventional vehicles, EVs do not generate the same high temperatures typically associated with internal combustion engines, but they do experience high-speed and high-torque operations. This results in unique tribological challenges that must be addressed to ensure the longevity and performance of EV components. For instance, the high-speed rotation of electric motors can lead to increased shear stresses and wear, requiring lubricants that can maintain stability and performance over a wide range of speeds and temperatures.

Testing of lubricants for EVs involves simulating real-world operating conditions in a controlled laboratory environment. This typically includes using tribometers to assess the lubricants' frictional and wear characteristics under varying loads, speeds, and temperatures. One common method is the pin-on-disc test, which evaluates the interaction between a rotating disc and a stationary pin coated with the lubricant. This test provides valuable insights into the COF, wear rates, and the lubricant's ability to form protective films that prevent metal-to-metal contact.

In addition to mechanical stresses, EV lubricants must also withstand electrical stresses due to the presence of electric fields in drivetrains. A study using a block-on-ring configuration on a Bruker UMT TriboLab demonstrated that the presence of electrical voltages can potentially increase wear on tribopairs, suggesting that electrification significantly affects the tribological performance of lubricants used in EV drivetrains.<sup>1</sup> Electrified tribotesting is crucial to accurately assess the electrical conductivity and potential for electrical corrosion of lubricants under realistic conditions, factors particularly important in preventing electrical pitting and ensuring the lubricant's long-term effectiveness.

While the integration of electric voltage in tribotesting setups can offer valuable insights into the influence of current on lubricating conditions, there are several common barriers to the widespread use of electrified tribotesting. These barriers include: (a) complexity introduced by the interaction of electric fields with the tribological system requires specialized equipment and protocols for electrified tribotesting; (b) setting up and maintaining electrified tribometers may require additional expertise and resources; and (c) ensuring the safety and reliability of electrified tribotesting setups is crucial to prevent accidents and ensure the validity of experimental results.

This application note offers an experimental investigation into the changes in friction and wear behavior of sliding contacts due to external electrification, using an accessible ball-on-disc Bruker UMT TriboLab setup. The study effectively identifies the significant effects of temperature, load, and voltage on the friction and wear behavior of various EV lubricants. The findings reveal important relationships between these factors and their impact on friction and wear, paving the way to address the critical gap in current tribological testing methodologies for EV lubricants.

## **An Accessible Setup for Electrified Tribotesting**

Bruker's UMT TriboLab is a versatile, modular tribometer capable of performing a wide range of tribological tests, including pin-on-disc, reciprocating, and block-on-ring configurations. It supports custom test setups and protocols, enabling tailored experiments to meet specific research and development needs, such as electrified tribotesting. Equipped with high-precision sensors, the tribometer can measure friction forces, wear depth, and electrical parameters simultaneously, offering real-time insights into the interaction between electrical and tribological factors.

UMT TriboLab is one of very few commercial electrified tribometers, and it offers several significant benefits for reliable and comprehensive electrified friction and wear testing:

- **Advanced Testing Capabilities:** With multiple testing modes and advanced environmental control, UMT TriboLab allows testing under a range of conditions, including temperature variations and the presence of AC and/or DC electrification. Its ability to conduct tests in lubricated, dry, or submerged environments makes it ideal for comprehensive tribological studies that simulate real-world operating conditions.
- **Standards Compliance:** UMT TriboLab enables standard tribology tests (ASTM, DIN, ISO, etc.) while applying electrical currents and voltages, facilitating compliance with industry requirements.
- **Precision and Accuracy:** The tribometer offers precise control over test parameters such as load, speed, temperature, and electrical conditions, accurately simulating the conditions materials face in practical applications. High-resolution sensors ensure accurate measurement of friction, wear, and other tribological properties, leading to consistent and reproducible results.
- **Upgradeability:** Existing non-electrified UMT TriboLab platforms can be seamlessly upgraded to include electrified testing capabilities, and new testing modules can be added at any time.

### Electrified Ball-on-Disc Testing of Two EV Lubricants

In this study, the ball-on-disc configuration was chosen for its robustness in closely simulating real-world applications involving sliding or rolling contact, such as bearings, gears, and other mechanical components. This setup allows precise control over contact conditions, including load, speed, and temperature, while maintaining a uniform electric field across the contact surface, as evidenced in the literature.<sup>2</sup>

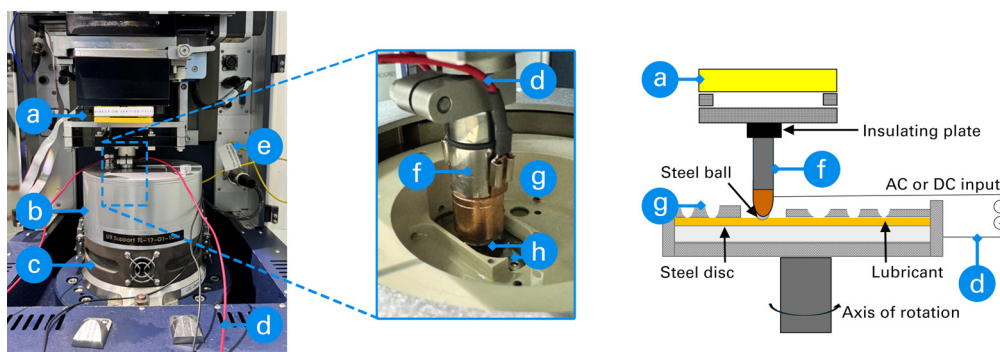


FIGURE 1

Ball-on-disc setup on a UMT TriboLab equipped with external electrification source. Labels indicate: (a) Bruker-patented 3D force/friction sensor, (b) heating chamber, (c) high-speed rotary drive, (d) 4-wire connection, (e) temperature sensor, (f) ball holder with beryllium copper contact ring, (g) disc holder with lid featuring circulation holes, and (h) sliding contact interface.

Figure 1 displays the complete assembly of the electrified ball-on-disc setup on the UMT TriboLab tribometer with locations of applied potentials and temperature measurement points. In this setup, a steel ball is loaded against a rotating disc submerged in 12 mL of lubricant within the disc holder. An AC or DC power supply was connected on one side to the ball holder, which was in contact with the ball, and on the other side to the contact points on the rotary drive, to induce external electricity during sliding. Both the ball and disc are electrically isolated from the test instrument to ensure that the applied potential is restricted to the interface between the ball and the disc, passing through the lubricant film. The electrical isolation is crucial to prevent unintended electrical pathways that could potentially damage the instrument's components and electronics.

The ball-on-disc setup was placed in an enclosed heating chamber, which enables test temperatures up to 250°C. A temperature sensor, integrated with the rotary drive, monitors the test temperature. To address the challenges of high-speed testing generating a liquid vortex, the disc holder features a lid with circulation holes designed to minimize lubricant loss while ensuring effective lubricant circulation at speeds up to 5000 rpm.

In the present work, samples consisted of an 52100-alloy steel ball (6.35 mm diameter) and disc (69.85 mm diameter, surface  $Ra = 8 \mu\text{m}$ ). The friction and wear performance both at room temperature and upon heating of two commercially available lubricants formulated for EV applications (called Lubricant A and Lubricant B), under both unelectrified and electrified conditions (DC: 0 A, 0.5 A, 1.5 A, and 3.0 A; AC: 0 A, 0.5 A, 2.0 A), were evaluated in terms of wear scar circumference and COF.

### Relationship between Friction, Wear, and Electrification

Figure 2 shows the friction coefficient and wear scar diameter under various test conditions in Lubricant A. COF increased significantly, by over 40%, when comparing between unelectrified and initial electrified conditions (Figure 2e, 0 to 0.5 A). The COF then gradually increased with the increase of DC electrification. These changes are attributed to the chemical properties of the lubricant. The presence of electrical current can alter the lubricant film thickness. Electricity may enhance the adsorption or desorption of polar additives and stimulate or suppress redox reactions at the contact interface.

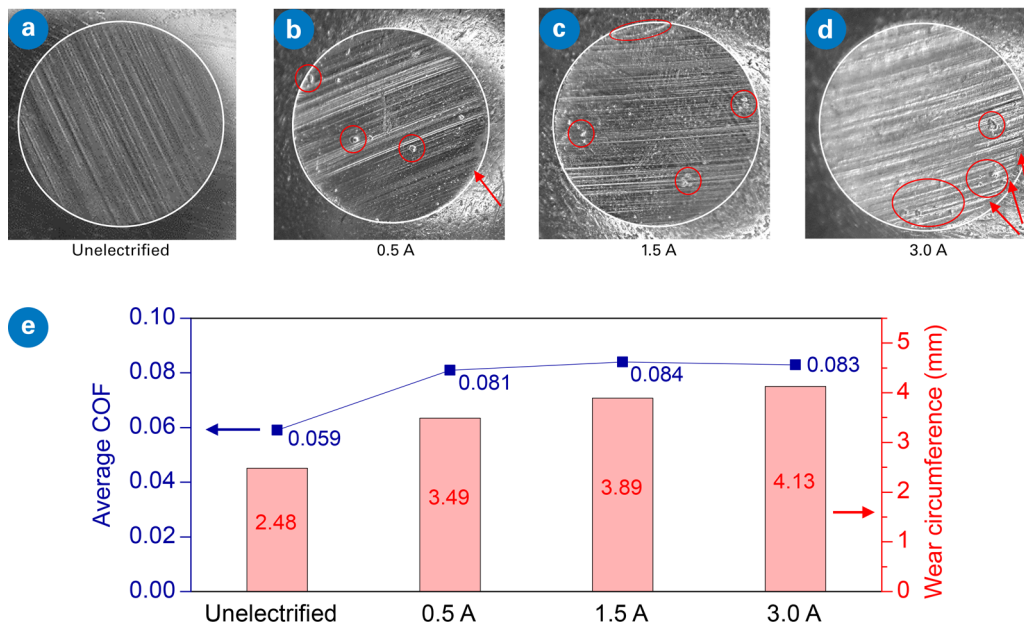
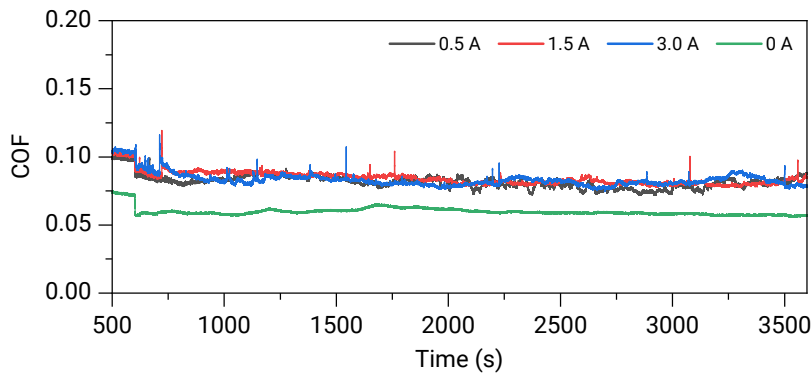


FIGURE 2

Steel pair (a–d) wear and (e) COF at room temperature under varying DC current magnitudes in Lubricant A (applied force = 120 N, sliding speed = 1000 rpm, sliding duration = 1 h). The red circles highlight the spark pits observed on the wear scars, while the red arrows indicate the uneven scrap edges present on the ball specimen.

Wear scars observed in both unelectrified and electrified tests exhibited abrasive wear marks aligned with the sliding direction (Figure 2a–d). Notably, the wear scars from the electrified tests were up to 67% larger in circumference. These marks are primarily caused by abrasion from the asperities of the countersurface and loose debris. The wear scars produced by electrification produced spark pits due to electrical erosion during sliding contact. In addition, the wear scars resulting from electrification at 1.5 A and 3 A displayed scrapped edges, where portions of the material chipped off, leaving behind uneven edges. This suggests that electrification softened the material, leading to a higher degree of third-body abrasive wear during mechanical scraping.



**FIGURE 3**

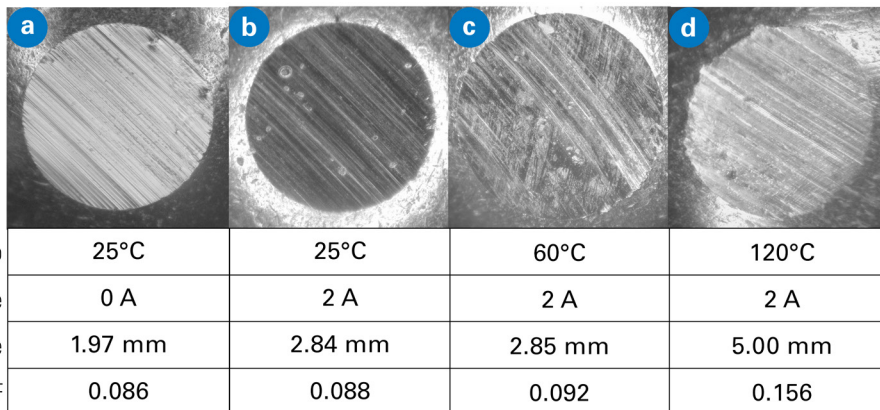
COF versus sliding duration at room temperature under various DC currents for Lubricant A (applied force = 120 N, sliding speed = 1000 rpm, sliding duration = 3000 s).

The comparison of COF changes throughout the test duration (Figure 3) indicates that electrification leads to noticeable variations in the COF trend. In the unelectrified condition, COF remains relatively low and stable, ranging from 0.05 to 0.06 throughout the sliding duration. Under the 0.5 A test condition, the COF starts higher than in the unelectrified state and exhibits an increasing trend with significant noise and variability. This suggests that electrification may increase adhesion between the contact surfaces by altering surface charges, thereby contributing to a higher COF. For the 1.5 A and 3.0 A conditions, COF values are relatively stable, approximately 0.08, with the latter being slightly higher.

Thermal effects from electrification can lead to localized softening of materials, resulting in increased deformation and friction, which is especially noticeable at higher current levels. These observations suggest that electrification affects both chemical and physical interactions at the interface, leading to increased friction compared to unelectrified conditions. Further studies, such as surface analysis and lubricant characterization, could provide more insight into these effects.

### Effect of Heating on Electrified Tribotesting

Figure 4 presents a comparison of the wear scars and friction coefficients observed in the heated and electrified tribotesting study. The introduction of a 2 A DC current at 25°C slightly increased the COF, but the wear scar circumference increased significantly from 1.97 mm to 2.84 mm. When the lubricant temperature rose to 60°C, the effect on the COF and wear scar was minimal. However, further heating to 120°C led to a significant increase in both the COF (to 0.156) and the wear scar circumference (to 5.00 mm). These COF and wear scar changes are likely due to a reduction in lubricant viscosity, resulting in thinner lubricant films and increased direct metal-to-metal contact. Additionally, high temperatures may enhance the electrical conductivity of the lubricant, altering charge distributions at the interface and contributing to increased wear, which creates noticeable uneven scrap edges.



**FIGURE 4**

Friction coefficient and wear scar circumference of 52100 ball specimens tested in Lubricant B at different temperatures (applied force = 90 N, sliding distance = 5000 m).

## Effects of AC Electricity

Under the influence of AC electricity, the tribopairs immersed in Lubricant A displayed varying COF and wear behavior, indicating a complex interaction between AC electrical effects and tribological performance. Figure 5 shows that the COF nearly doubles when 0.5 VAC is introduced but decreases as the voltage increases to 1.0 V and 2.0 V. While the wear scar is slightly smaller at 1.0 V compared to 0.5 V, it becomes larger at 2.0 V. This suggests that the AC field affects the material surface structure, leading to material removal and degradation. The reduction in COF may result from interface changes due to the formation of a lubrication film, the adsorption of charge-promoted ions from additives, and redox reactions promoting metal oxide formation, which results in a less severe boundary regime. However, these hypotheses require further chemical analysis, which is beyond the scope of this evaluation study.

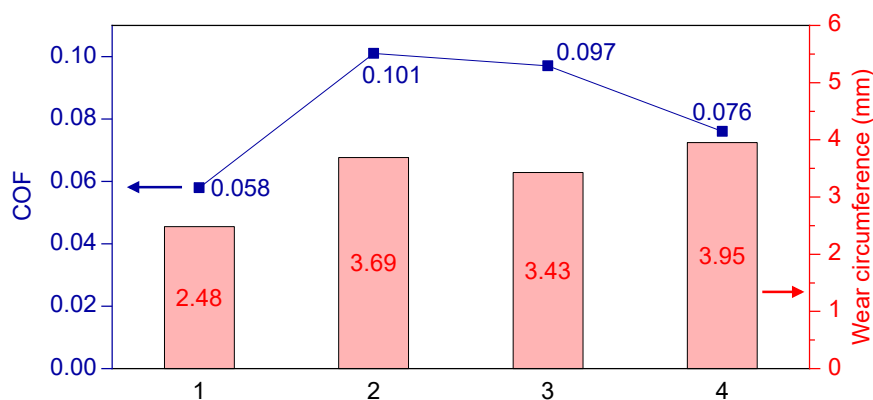


FIGURE 5

Friction coefficient and wear of 52100 steel pair under varying AC current in Lubricant A.

## Summary

In this application note, an electrically isolated ball-on-disc test configuration using Bruker's UMT TriboLab was presented to explore the effects of applied electrical potential on EV drivetrain fluids. This work focused on the COF and wear characteristics of 52100 steel under various loads, temperatures, and electrification conditions. Applying DC current during ball-on-disc testing led to significant changes in the tribological behavior of 52100 steel pairs, with notable increases in both COF and wear scar circumference when DC voltage was applied across the contact interface. The combination of high temperatures and DC electrification significantly intensified wear and friction, suggesting potential thermal softening and oxidation effects at the sliding interface. Conversely, the introduction of AC voltage initially increased both COF and wear; however, as the voltage further increased, the COF began to decrease while the wear scar continued to grow. This exploratory work in the field of EV tribology testing demonstrates that the presence of electrical voltage or current can alter the COF and wear of tribological pairs.

Although the effects of electrical conditions on friction and wear are complex, they require a comprehensive approach to experimental design and analysis. UMT TriboLab is ideal for electrified tribotesting of EV lubricants because of its accessibility, standards-based test methods, advanced real-time measurement capabilities, and precise simulation of real-world conditions.

## References

1. Lee, P. M., Sanchez, C., Frazier, C., Velasquez, A., & Kostan, T. (2023). Tribological evaluation of electric vehicle driveline lubricants in an electrified environment. *Frontiers in Mechanical Engineering*, **9**, 1215352. DOI: 10.3389/fmech.2023.1215352
2. Cao-Romero-Gallegos, J. A., Taghizadeh, S., Aguilar-Rosas, O. A., Dwyer-Joyce, R. S., & Farfan-Cabrera, L. I. (2024). The effect of electrical current on lubricant film thickness in boundary and mixed lubrication contacts measured with ultrasound. *Friction*, **12**, 1882-1896. DOI: 10.1007/s40544-024-0890-7

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