Original Article

Slip Behaviour of Epoxy-Based Safety Shoe Soles Manufactured with Mango Dry Leaf and Olive Dry Leaf Powders for Workplace Applications

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Abstract

Ensuring safety in laboratory environments is crucial due to frequent slip-related hazards caused by water, oil, and chemical spills. This study investigates the development and performance of epoxy-based safety shoe soles reinforced with mango dry leaf (MDL) and olive dry leaf (ODL) powders derived from agricultural waste. The fillers (10 wt.%) were prepared through washing, drying, grinding, and sieving, and uniformly incorporated into the epoxy matrix before curing at room temperature for 48 hours. The static slip resistance of the resulting composites was evaluated under four representative laboratory conditions: dry, water-wet, oil-lubricated, and mixed water–oil contaminated surfaces, using a calibrated friction testing apparatus.

The results showed that the ODL-filled epoxy composite exhibited the highest static coefficient of friction under dry conditions $\mu = 0.99 \pm 0.03$, while the MDL-filled epoxy achieved superior performance under water-wet conditions $\mu = 0.51 \pm 0.01$. Under the most challenging mixed water–oil condition, the unmodified epoxy demonstrated the highest friction $\mu = 0.59$, followed by the MDL $\mu = 0.45$ and ODL $\mu = 0.40$ composites. The incorporation of natural leaf powders significantly enhanced surface roughness and micro-mechanical interlocking, leading to higher slip resistance compared with neat epoxy and conventional

Keywords: Epoxy-Based Shoe Soles, Mango Dry Leaf, Olive Dry Leaf, Friction Testing Apparatus, Workplace Safety

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1 INTRODUCTION

Modern laboratory environments—whether chemical, biological, pharmaceutical, or engineering laboratories—are governed by strict safety protocols due to the nature of work involving hazardous materials, delicate instrumentation, and precision-based activities. Among the many risks encountered in these settings, slip-related accidents are a persistent and often underestimated hazard, particularly in laboratories where liquid spills and surface contaminants are commonplace. These incidents pose serious threats not only to human safety but also to valuable equipment and ongoing experimental procedures [1,2].

Laboratory floors are often finished with epoxy resin coatings because of their impermeability, chemical resistance, and ease of cleaning [3,4]. However, these smooth, polished surfaces can exhibit poor traction when wet, oily, or contaminated,

posing slip hazards [5,6]. These surface conditions are frequently encountered in laboratories due to the use of solvents, distilled water, oils, cleaning agents, and biological media. Consequently, there is a growing need for safety footwear that offers superior slip resistance tailored to such specialized environments.

Footwear soles intended for use on smooth epoxy or tile floors must maintain slip resistance even under contaminated conditions. While rubber and synthetic soles with tread patterns provide good friction on dry surfaces, their effectiveness decreases significantly when water, oil, or mixed contaminants are present, leading to increased slip risk on such smooth flooring types [7]. Furthermore, their performance deteriorates over time due to wear, material fatigue, and environmental exposure. As such, there is a demand for new material formulations that integrate anti-slip functionality at the material microstructure level, rather than relying solely on macro-texturing or patterning.

Polymer composite technology offers pathways to improve surface and mechanical properties through the incorporation of fillers into the matrix, including bio-based materials that enhance mechanical, thermal, and surface characteristics [8,9]. In epoxy composites, bio-fillers can modify the microstructure and interfacial energy of the cured matrix, increasing micro-roughness and improving frictional behaviour under both dry and lubricated conditions [10].

This study explores two novel natural reinforcements—dried mango leaf powder and dried olive leaf powder—as functional fillers for epoxy-based composites aimed at enhancing slip resistance in laboratory footwear soles. While these specific bio-fillers have not been extensively studied before, previous research has shown that natural agricultural fibers are rich in cellulose, hemicellulose, and lignin, which enable good interaction with polymer matrices [11,12]. The environmental relevance of such fillers is twofold. First, they enable waste valorization by transforming biomass into high-value functional materials and reducing dependence on synthetic, petroleum-based additives, which aligns with global sustainability frameworks and national strategies promoting resource efficiency [13]. Such goals are consistent with initiatives like Saudi Vision 2030, which emphasizes sustainable economic development and efficient resource use. Additionally, bio-fillers offer inherent advantages such as low cost, biodegradability, renewability, and reduced environmental footprint during production and end-of-life disposal [14,15].

Although considerable research has been conducted on natural-fiber composites in the automotive, packaging, and construction industries [16], there remains a noticeable gap in the literature regarding their functional performance in tribological applications such as slip resistance. The majority of existing studies focus on tensile, flexural, and impact properties, with limited attention to surface friction behavior or practical performance under realistic, contaminated conditions [17].

Furthermore, very few studies assess performance under multi-phase contamination (dry, water, oil, and water-oil mixtures), which are critical for accurately simulating laboratory spills and maintenance conditions. Regulatory standards such as ASTM D2047, ISO 13287, and EN 20345 emphasize the need to evaluate footwear across a range of surface contaminants to ensure safe design and reliable performance.

This study highlights the dual role of such natural reinforcements: improving safety performance while promoting environmental sustainability by valorizing agricultural residues. It highlights the bio-fillers' effectiveness in enhancing slip resistance on contaminated laboratory floors, promoting safety and sustainability while valorizing agricultural waste for advanced material design. The use of biodegradable and locally sourced materials aligns with broader goals of green engineering and circular economy practices. Consequently, this research advocates for the continued exploration of eco-friendly composite materials in the design and development of advanced safety footwear tailored for laboratory and other sensitive environments.

This study aims to fill this research gap by developing epoxy composite formulations with dried mango and olive leaf powders, investigating their static slip resistance under dry, wet, oily, and mixed contamination conditions, comparing them to standard epoxy and ceramic tiles used in laboratories, and exploring their potential as sustainable alternatives for laboratory safety footwear. By uniting sustainability with functionality, this research demonstrates a novel approach to protective footwear design, contributing both to worker safety and the advancement of green material technologies.

2 Materials and Methods

2.1 Materials Selection

Both mango and olive leaves were collected from local farms in Jazan region. The collected leaves (Mango dry leaves MDL and Olive dry leaves ODL, about 5 kg from each) were carefully washed with distilled water, followed by drying in an oven at 80°C for 24 hr. After drying, the leaves of each plant were separately ground using an electric blender to be converted into powders with small particles and were then sieved to achieve uniform particle size at 0.5 mm. The powders were stored in plastic bags in a dry place until use.

The selection of both agro-wastes was driven by environmental, mechanical, and functional considerations. The fillers are biodegradable, cost-effective, and readily available in agricultural regions, particularly in Saudi Arabia. Their micro-textured morphology offers the potential to enhance epoxy composites' grip, especially under liquid contamination.

2.2 Preparation of Test Samples

The epoxy resin and hardener were mixed in a 3:1 weight ratio (60 g resin to 20 g hardener). The bio-filler was slowly introduced into the epoxy mixture with a final ratio of 10 wt.% of either MDL or ODL powder. Each composite mixture was stirred continuously until homogeneous dispersion was achieved.

The composites were poured into 20 cm × 20 cm wooden molds (handmade) and left to cure at room temperature for 48 hours. Both filled and unfilled (control) epoxy panels were fabricated using the same protocol to ensure consistency across samples.

2.3 Experimental Conditions

The prepared panels were tested under four laboratory-relevant surface conditions designed to replicate typical contamination scenarios: a dry surface, a water-wetted surface, an oil-lubricated surface using light synthetic oil, and a mixed water-oil condition.

These scenarios replicate typical spill and contamination situations encountered in chemical, biological, and medical laboratory environments.

To apply the friction measurements a test sample with 5x5 cm2 of commercial safety shoes sole under the proposed testing conditions.

2.4 Frictional Characterization

The static coefficient of friction (CoF) was measured using a calibrated friction testing apparatus. The tests were conducted under a controlled normal load, simulating the pressure exerted by human footsteps. For each sample and surface condition, at least five measurements were averaged to ensure result reliability.

Friction data were analyzed to assess the impact of MDL and ODL powder reinforcements on slip resistance. The findings enable direct comparisons between epoxy composites with different natural fillers and conventional flooring materials such as ceramic tiles.

This experimental strategy supports the identification of optimal eco-composite formulations for lab footwear, promoting both safety and sustainable material practices.

3 Results and Discussion

This section analyzes the slip resistance behavior of epoxy resin composites reinforced with MDL and ODL powders, focusing on their use in laboratory safety footwear, where surface cleanliness, frequent liquid spills, and precision walking paths pose unique traction challenges.

The experimental results are interpreted using the static coefficient of friction (μ) as the central metric to evaluate the effectiveness of each composite under four environmental conditions: dry, wet (water-covered), oil-lubricated, and water-oil mixed surfaces.

3.1. Determination of static coefficient of friction under dry sliding conditions

The findings demonstrate that ODL-filled epoxy composites consistently outperformed other formulations, achieving the highest μ values across all conditions. This enhanced performance is linked to the surface roughness and micro-anchoring effect introduced by olive leaf particles. These particles exhibit higher surface irregularity and a denser fibrous structure, enabling them to resist slippage even under lubricated conditions.

The MDL composites also showed marked improvement over unfilled epoxy, though to a slightly lesser degree. Their moderate friction enhancement is attributed to the leaf structure, which, while effective, presents less pronounced surface disruption compared to ODL.

In comparing filled epoxy with ceramic tile and unmodified epoxy, the bio-filled composites demonstrate superior traction. Ceramic tiles consistently recorded the lowest μ values, highlighting their inherent slip-prone nature, especially when exposed to oils or cleaning agents.

Mechanistically, the observed frictional trends are explained by the filler-matrix interaction, dispersion quality, and particle geometry, all of which influence how the surface engages with contaminants. The mechanical interlocking facilitated by the fillers prevents fluid film formation, while the chemical composition of the bio-fillers may also contribute to surface energy alterations, affecting adhesion under wet conditions.

These insights establish that natural leaf powders, particularly ODL, can be effectively employed in the design of non-slip laboratory footwear, offering a sustainable, safe, and performance-oriented solution for sensitive indoor environments.

The dry sliding performance of various flooring materials is presented in Fig. 1, where the friction coefficient (μ) is plotted against sliding time. Error bars indicate the standard deviation (SD) from at least three independent measurements for each material. Among the tested samples, epoxy filled with ODL demonstrated the highest static friction coefficient $\mu = 0.99 \pm 0.03$, followed closely by epoxy filled MDL flooring at $\mu = 0.70 \pm 0.01$. The ceramic showed a significantly lower coefficient $\mu = 0.19 \pm 0.02$, while epoxy flooring exhibited value of $\mu = 0.58 \pm 0.01$.

These results are consistent with prior research demonstrating the role of natural fillers in improving the tribological performance of polymer composites. Previous studies have shown that incorporating bio-based fillers such as rice husk, sawdust, and lignocellulosic fibers into epoxy and other polymer matrices can enhance wear resistance and increase the coefficient of friction, primarily due to improved filler-matrix bonding, micro-mechanical interlocking, and increased surface roughness [18,19]. Reviews of natural fiber-reinforced composites further highlight that these fillers can significantly modify frictional behavior by altering the microstructure and interfacial properties of the composite, offering sustainable alternatives to synthetic additives for slip-resistant applications [20,21].

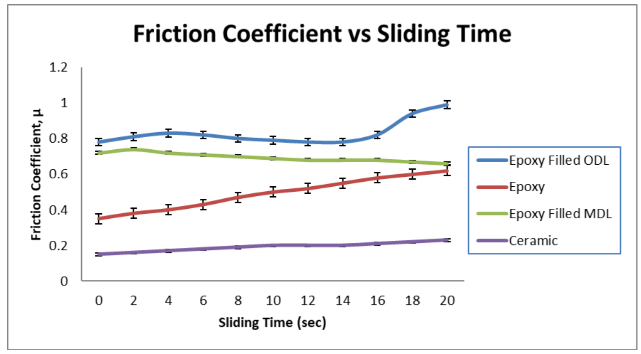

FIGURE 1. Comparison of the friction coefficient (μ) over sliding time for different epoxy composite floors under dry sliding conditions. Materials tested include epoxy reinforced with MDL, ODL, unmodified epoxy, and ceramic tiles.

3.2. Determination of static coefficient of friction of water-lubricated surfaces

The effect of water-lubricated conditions on the slip performance of epoxy-based composite flooring materials is illustrated in Fig. 2. Error bars indicate the standard deviation (SD) calculated from at least three independent measurements for each material. The results indicate that epoxy filled with ODL achieved the highest static coefficient of friction $\mu = 0.51 \pm 0.01$, closely followed by epoxy filled with MDL at $\mu = 0.49 \pm 0.02$. The unmodified epoxy recorded a significantly lower coefficient ($\mu = 0.43 \pm 0.04$), while the ceramic flooring exhibited the lowest slip resistance with a coefficient of friction of $\mu = 0.20 \pm 0.02$. confirming its susceptibility to slipping when exposed to water.

These findings, including the observed variability, reinforce the beneficial role of natural fillers in enhancing surface roughness and mechanical interlocking even in wet environments, where conventional materials such as ceramics typically suffer from reduced traction. The slight superiority of MDL over ODL in wet conditions may be attributed to differences in particle morphology or filler–matrix bonding efficiency. Overall, the bio-filled composites significantly outperformed both neat epoxy and ceramic, highlighting their potential as safe, sustainable flooring alternatives in moisture-prone industrial settings. These results are consistent with prior research indicating that natural bio-fillers can enhance the tribological performance of polymer composites by increasing surface roughness, improving filler–matrix adhesion, and promoting micro-mechanical interlocking [18,19]. Such mechanisms are well-documented in epoxy systems filled with agricultural residues like rice husk and sawdust, which have demonstrated improved wear resistance and stable frictional behaviour [18]. Reviews further emphasize that natural fiber and bio-filler reinforcements modify the composite microstructure and interfacial properties, offering sustainable alternatives to synthetic additives for friction-critical applications [20,21]. In contrast, conventional ceramic tile surfaces are well-known for poor slip resistance under wet conditions, underscoring the need for advanced composite solutions. Notably, differences in filler morphology and surface energy can significantly influence wet-lubricated slip behavior, suggesting that the slight performance variation observed between MDL- and ODL-filled systems may be attributed to such morphological and interfacial factors [22]. Collectively, these insights support the development of bio-filled epoxy flooring materials as safe, sustainable options for moisture-prone industrial environments.

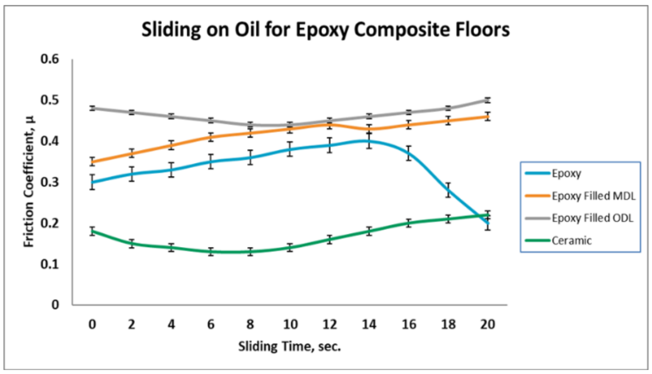

FIGURE 2. Friction coefficient (μ) variation with sliding time for epoxy composite floors under wet sliding conditions. Samples include epoxy filled with MDL, epoxy filled with ODL, unmodified epoxy, and ceramic tiles.

3.3. Determination of static coefficient of friction of mixed water/oil surfaces

The influence of a mixed water/oil surface condition on the slip behavior of epoxy-based composites and conventional materials is illustrated in Fig. 3. Under this most challenging scenario, unmodified epoxy exhibited the highest static coefficient of friction μ = 0.59, indicating better retention of slip resistance compared to the other tested surfaces. The epoxy composite filled with MDL followed with a coefficient of 0.43, while the epoxy composite filled with ODL recorded a lower value of 0.39. The ceramic surface, consistent with previous tests, showed the poorest slip performance with the lowest friction coefficient of 0.19.

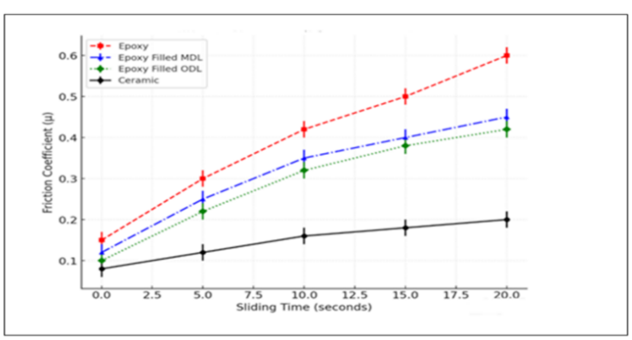

FIGURE 3. Variation of the friction coefficient (μ) with sliding time for epoxy composite floors under combined water/oil (wet and oily) sliding conditions. The materials tested include epoxy filled with MDL, ODL, unmodified epoxy, and ceramic flooring.

These findings are consistent with established evidence showing that oil–water contamination can substantially reduce slip resistance in flooring systems, posing a worst-case scenario for many materials. For example, surface safety studies have documented that mixed lubrication films disrupt contact mechanics and reduce available friction compared to dry or purely wet conditions [23,24]. In this study, MDL- and ODL-filled epoxy composites, which demonstrated excellent performance under dry and purely wet conditions, exhibited significant drops in static coefficient of friction under oil–water conditions. This decline supports the interpretation that the lubricating film in oil–water mixtures interferes with the micro-mechanical interlocking and surface roughness benefits typically provided by natural fillers. Such results highlight the need for advanced design strategies, including possible surface treatments or additives, to maintain effective slip resistance in highly contaminated industrial environments.

3.4. Theoretical Modeling of Friction Behavior in Epoxy Composites Reinforced with Dried Mango and Olive Leaf Powders

In laboratory settings, where the risk of slipping is amplified by frequent spills of water, oil, and chemical solutions, footwear must be designed with precision-engineered traction properties. Epoxy composites reinforced with dried MDL and ODL powders offer a sustainable pathway to improve anti-slip performance. To guide their development, a detailed theoretical understanding of frictional behavior is essential.

Friction modeling in this context is grounded in contact mechanics, where the interaction between the shoe sole and the laboratory floor depends on the distribution of stresses across surface asperities [25,26]. The addition of MDL and ODL bio-fillers increases surface roughness and modifies asperity morphology within the epoxy matrix, thereby enhancing micro-mechanical interlocking with the floor surface and altering local stress distributions. This mechanism helps explain the observed improvements in slip resistance under certain conditions.

The coefficient of friction depends on surface energy, roughness, and elasticity—all of which are modified by the bio-filler content. Theoretical formulations must accommodate these variations, especially under contaminated conditions where fluid films or thin surface layers can alter the effective friction coefficient [27,28].

As laboratory shoes are routinely exposed to moisture and chemicals, detailed wear analysis becomes essential. Wear mechanisms such as abrasive wear, micro-fatigue, and chemical degradation at polymer–filler interfaces can reduce slip resistance over time [29,30]. Accurate predictive models must therefore integrate these mechanisms to ensure long-term durability and to optimize the composition of bio-filled epoxy systems for enhanced performance.

Lubrication theory is critical when evaluating laboratory flooring systems, as it provides a framework for understanding how contaminants can induce transitions between lubrication regimes [31]. Modeling these interactions enables researchers to predict frictional behavior and informs the design of filler morphology to optimize surface roughness for improved dry and wet traction.

Environmental modeling is essential, as laboratory conditions can vary significantly in temperature and humidity, affecting the viscoelastic properties of the polymer matrix and the moisture absorption behavior of natural fillers [32,33]. Such variations alter the composite's frictional response and must be incorporated into predictive models to ensure reliable performance in real-world settings.

Computational tools like finite element analysis (FEA) and molecular dynamics (MD) enable in-depth simulation of interfacial interactions at macro and nano scales, providing insight into stress evolution and performance under sliding loads [34,35]. Such modeling approaches are critical for understanding and optimizing tribological behavior in engineered surfaces.

By building such robust theoretical models, researchers can simulate and optimize epoxy composite soles reinforced with MDL and ODL powders—supporting the development of safety footwear that meets both environmental and functional performance demands in laboratory environments [36,37].

4 Conclusion

This study investigated the slip resistance behavior of epoxy-based composite flooring materials reinforced with mango dry leaf (MDL) and olive dry leaf (ODL) powders under four laboratory-relevant conditions: dry, water-wet, oil-lubricated, and mixed water–oil surfaces. The results showed that the inclusion of natural bio-fillers significantly improved friction performance in dry and wet environments compared to unmodified epoxy and ceramic flooring.

Under dry conditions, the ODL-filled epoxy composite exhibited the highest static coefficient of friction $\mu = 0.99 \pm 0.03$, followed by the MDL-filled composite $\mu = 0.88 \pm 0.01$. The unmodified epoxy and ceramic surfaces recorded markedly lower values of $\mu = 0.51 \pm 0.02$ and $\mu = 0.38 \pm 0.01$, respectively. Similarly, under water-wet conditions, the ODL composite achieved the highest friction level $\mu = 0.51 \pm 0.01$, closely followed by the MDL composite $\mu = 0.49 \pm 0.02$, while the unmodified epoxy $\mu = 0.43 \pm 0.04$ and ceramic flooring $\mu = 0.20 \pm 0.02$ demonstrated significantly reduced slip resistance.

In contrast, when exposed to oil-lubricated and mixed water–oil conditions, all tested surfaces experienced a noticeable decrease in friction due to the formation of lubricating films. Under the mixed contamination condition, the unmodified epoxy showed the highest friction value $\mu = 0.59$, followed by the MDL-filled composite $\mu = 0.45$ and the ODL-filled composite $\mu = 0.40$, whereas ceramic flooring again recorded the lowest coefficient $\mu = 0.19$.

These outcomes suggest that natural fillers, particularly MDL and ODL powders, are highly effective in enhancing surface roughness and mechanical interlocking, thereby increasing slip resistance under dry and wet conditions. However, their performance declines significantly in oil-contaminated or mixed environments, where the fluid film likely suppresses the fillerinduced micro-roughness.The superior dry and wet traction of the MDL and ODL composites underscores their practical viability as sustainable, high performance materials for safety footwear in laboratory environments. Their use also promotes environmental responsibility through the valorization of agricultural waste, contributing to circular economy practices and Saudi Vision 2030.

5 Recommendations

Based on the results and insights gained from this study, the following recommendations are proposed:

5.1 Enhanced Filler Engineering

Explore surface modification techniques (e.g., alkali treatment, silane coupling agents) to improve the interfacial bonding and oil resistance of the fillers, especially under mixed water-oil conditions.

5.2 Hybrid Filler Strategies

Investigate the synergistic effects of blending MDL and ODL in different ratios or combining them with inorganic micro-fillers (e.g., silica) to improve friction retention under lubrication.

5.3 Optimizing Filler Loading

Conduct a parametric study on varying filler weight fractions (e.g., 5%, 15%, 20%) to determine the optimal concentration that balances slip resistance and mechanical properties.

5.4 Surface Topography Characterization

Use Scanning Electron Microscopy (SEM) and 3D surface profilometry to quantify surface roughness and correlate it with frictional behavior under each test condition.

5.5 Long-Term Durability Testing

Include cyclic wear, fatigue, and chemical exposure testing to evaluate the long-term stability of the composites in actual lab environments.

5.6 Standardized Performance Benchmarking

Validate the composite soles against international standards such as ASTM F2913, ISO 13287, and EN 20345 to support their integration into certified safety footwear products.

5.7 Environmental and Economic Assessment

Perform a life-cycle assessment (LCA) and cost-benefit analysis to quantify the ecological and economic advantages of using MDL and ODL fillers over synthetic alternatives.

5.8 Expansion to Other Applications

Extend the use of these composites beyond footwear to include anti-slip surfaces in medical labs, food processing facilities, and wet public environments.

References

1. ASTM D2047. (2020). Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces. ASTM International.
2. Ghosh, A., Buckley, D., & Maiti, J. (2018). Slip, trip, and fall (STF) incidents: A systematic review of their circumstances and interventions. Safety Science, 112, 234–249. https://doi.org/10.1016/j.ssci.2018.01.002.
3. ASTM International. (2018). ASTM F3010-18: Standard Practice for Two-Component Resin Based Membrane-Forming Moisture Mitigation Systems. West Conshohocken, PA: ASTM International.
4. Lab Manager Magazine. (2016). Floor Coatings in Laboratories: Performance and Maintenance Considerations. Retrieved fromhttps://www.labmanager.com/laboratory-flooring-19628.
5. ASTM International. (2020). ASTM D2047-20: Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces. West Conshohocken, PA: ASTM International.
6. Choi, Y. S., & Kim, H. J. (2015). Slip resistance of epoxy-coated industrial flooring under wet and oily conditions. Safety Science, 80, 185–192. https://doi.org/10.1016/j.ssci.2015.07.018.
7. Li, K., & Chen, J. (2015). Influence of contaminants on slip resistance of flooring surfaces. Applied Ergonomics, 50, 203–210.
8. John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. Carbohydrate Polymers, 71(3), 343–364. https://doi.org/10.1016/j.carbpol.2007.05.040.
9. Rajak, D. K., Pagar, D. D., Menezes, P. L., & Linul, E. (2019). Fiber-reinforced polymer composites: Manufacturing, properties, and applications. Polymers, 11(10), 1667.
10. Gupta, A., & Kumar, R. (2020). Effect of bio-fillers on

tribological properties of epoxy composites. Journal of Materials Research and Technology, 9(6), 14556–14563.

11. Mohanty, A. K., Misra, M., & Drzal, L. T. (2002). Sustainable bio-composites from renewable resources: Opportunities and challenges. Journal of Polymers and the Environment, 10(1–2), 19–26.

12. Huda, M. S., Drzal, L. T., Misra, M., & Mohanty, A. K. (2005). Natural fiber reinforced polymer composites and their mechanical properties. Composites Science and Technology, 65(3–4), 551–564.

13. Al-Oqla, F. M., & Sapuan, S. M. (2014). Natural fibre reinforced polymer composites in industrial applications: feasibility of date palm fibres for sustainable automotive industry. Journal of Cleaner Production, 66, 347–354.

14. Pickering, K. L., Efendy, M. G. A., & Le, T. M. (2016). A review of recent developments in natural fibre composites. Composites Part A: Applied Science and Manufacturing, 83, 98–112.

15. Ticoalu, A., Aravinthan, T., & Cardona, F. (2010). A review of current development in natural fiber composites. Southern Region Engineering Conference, 113–117. Retrieved from.

16. Jawaid, M., & Abdul Khalil, H. P. S. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. Carbohydrate Polymers, 86(1), 1–18.

17. D'Souza, N., & Deodhar, S. (2018). Biowaste valorization: A review of waste-derived reinforcements in polymer composites. Waste and Biomass Valorization, 9(7), 1043–1055.

18. Gupta, A., & Kumar, R. (2020). Effect of bio-fillers on tribological properties of epoxy composites. Journal of Materials Research and Technology, 9(6), 14556–14563.

19. Samal, S. S., & Biswas, S. (2016). Sliding wear and friction characteristics of epoxy hybrid composites reinforced with natural fiber and micro-fillers. Wear, 368–369, 384–393.

20. Hossain, M. K., et al. (2019). Effects of natural fillers on mechanical and tribological properties of polymer composites: A review. Construction and Building Materials, 209, 748–764.

21. Rajak, D. K., Pagar, D. D., & Menezes, P. L. (2019). Tribological behaviour of natural fiber reinforced polymer composites: A review. Journal of Reinforced Plastics and Composites, 38(18), 835–853.

22. Tan, Z., Li, W., Wang, X., & Zhang, J. (2021). Role of particle morphology on wet-slip frictional properties of polymer composites. Tribology International, 155, 106798. https://doi.org/10.1016/j.triboint.2021.106798

23. Chang, W.-R. (1998). The effect of surface roughness on slip resistance of floors under contamination. Safety Science, 29(2), 89–105.

24. ASTM F2913-19. (2019). Standard Test Method for Measuring the Coefficient of Friction for Footwear. ASTM International.

25. Popov, V. L. (2010). Contact Mechanics and Friction: Physical Principles and Applications. Springer. https://doi.org/10.1007/978-3-642-10803-7.

26. Johnson, K. L. (1985). Contact Mechanics. Cambridge University Press. https://doi.org/10.1017/CBO9781139171731.

27. Persson, B. N. J. (2000). Sliding Friction: Physical Principles and Applications. Springer. https://doi.org/10.1007/978-3-662-04283-0.

28. Nosonovsky, M., & Bhushan, B. (2007). Multiscale Dissipative Mechanisms and Hierarchical Surfaces: Friction, Superhydrophobicity, and Biomimetics. Springer. https://doi.org/10.1007/978-3-540-36806-2.

29. Archard, J. F. (1953). Contact and rubbing of flat surfaces. Journal of Applied Physics, 24(8), 981–988. https://doi.org/10.1063/1.1721448.

30. Blau, P. J. (2009). Friction Science and Technology: From Concepts to Applications (2nd ed.). CRC Press. https://doi.org/10.1201/9781420074055.

31. Hamrock, B. J., Schmid, S. R., & Jacobson, B. O. (2004). Fundamentals of Fluid Film Lubrication (2nd ed.). CRC Press. https://doi.org/10.1201/9780849391844.

32. Mang, T., & Dresel, W. (2017). Lubricants and Lubrication (2nd ed.). Wiley-VCH. https://doi.org/10.1002/9783527643735.

33. Persson, B. N. J. (2007). Sliding Friction: Physical Principles and Applications (2nd ed.). Springer. https://doi.org/10.1007/978-3-540-36874-1.

34. Komvopoulos, K. (2003). Surface engineering and microtribology for MEMS. Wear, 254(11–12), 1100–1109. https://doi.org/10.1016/S0043-1648(03)00386-1.

35. Lu, X., Wang, Q. J., & Zhu, D. (2007). A finite element method study of subsurface stress and strain in sliding contacts of layered elastic–plastic solids. Tribology International, 40(7), 1025–1033.

36. Bhushan, B. (2013). Introduction to Tribology (2nd ed.). Wiley. https://doi.org/10.1002/9781118403010.

37. Hutchings, I. M., & Shipway, P. (2017). Tribology: Friction and Wear of Engineering Materials (2nd ed.). Butterworth-Heinemann. https://doi.org/10.1016/C2014-0-04096-1.