Global Education Journal
Vol. 4, 1 (January-April, 2026), pp. 165-172
EISSN: 2986-6529, DOI: https://doi.org/10.59525/gej.1367

Analysis of Sliding Gate Mixer Machine as a Context for Engineering Learning

Mochamad Saleh[1]

[1] Universitas Sunan Giri Surabaya, Indonesia; moch.sholeh70@gmail.com

ARTICLE INFO

Keywords:

Cement Mixer, Engineering Learning, Friction Coefficient, Pneumatic Actuator, Sliding Gate.

Article history:

Received 2025-11-14
Revised 2025-12-18
Accepted 2026-01-28

ABSTRACT

Sliding gate systems in cement mixer machines are critical components for regulating material flow; however, their performance is often constrained by excessive friction and shear forces, particularly under maximum load conditions. Empirical observations at PT FOCON Mojokerto revealed that the sliding gate fails to operate smoothly when the hopper load reaches one ton, leading to increased actuation force demand and overheating of the pneumatic cylinder. This study aims to analyze the shear forces acting on the sliding gate based on different material contact configurations and to determine the optimal pneumatic cylinder bore diameter for efficient operation. The research employs a quantitative analytical approach grounded in classical friction theory and pneumatic force analysis, using field-observed loading conditions and validated material friction coefficients. The results demonstrate that metal-to-metal contact generates the highest shear force (925 kg), whereas the use of nylon combined with grease lubrication reduces the shear force significantly to 187.5 kg, enabling a reduction in the required pneumatic cylinder bore diameter from 155 mm to 70 mm at a working pressure of 5 bar. These findings confirm that appropriate material selection and lubrication substantially improve sliding gate performance and actuator efficiency. The study concludes that polymer-based, lubricated sliding interfaces provide a practical and economical alternative to imported components. Scientifically, this research contributes by explicitly linking tribological material properties to pneumatic actuator sizing in industrial sliding gate design.

Corresponding Author:
Mochamad Saleh
Universitas Sunan Giri Surabaya, Indonesia; moch.sholeh70@gmail.com

1. INTRODUCTION

In modern bulk material handling systems, sliding gate mechanisms play a critical role in regulating material flow between storage units and processing equipment. Ideally, a sliding gate installed in a cement mixer system is expected to operate smoothly, reliably, and efficiently under varying load conditions, ensuring uninterrupted material transfer while minimizing mechanical resistance, energy consumption, and component wear. From an engineering design perspective, an optimal sliding gate system should exhibit low frictional resistance, stable actuation forces, and thermal safety of the actuator, particularly when operated continuously in industrial environments (Meriam & Kraige, 2015; Hibbeler, 2016). In pneumatic-driven systems, this ideal condition further requires accurate actuator sizing and appropriate material selection to prevent overloading and inefficiency.

Empirically, however, industrial sliding gate systems especially those used in cement and powder-based material processing often deviate significantly from these ideal conditions. Several recent studies (2020–2025) have reported that sliding gates operating under high material loads frequently suffer from excessive friction, unstable motion, actuator overheating, and premature mechanical failure (Das, 2023; Bhilare et al., 2025). Cement materials, characterized by high density, abrasiveness, and particle interlocking behavior, impose substantial normal forces on sliding surfaces, thereby increasing shear resistance at the contact interface (Kitazume, 2021). As a result, actuators are often forced to operate near or beyond their design limits, leading to efficiency losses and maintenance challenges. These empirical findings indicate that friction-induced shear forces remain a dominant but often underestimated factor in sliding gate performance.

In the specific context of PT FOCON Mojokerto, empirical observations revealed that the sliding gate of the cement mixer machine fails to operate smoothly when the hopper material reaches its maximum capacity of approximately one ton. Under this loading condition, the gate experiences severe resistance during horizontal motion, causing delayed or incomplete opening and closing cycles. Moreover, the pneumatic cylinder driving the gate was observed to experience abnormal temperature increases during operation, indicating excessive force demand and inefficiencies in the pneumatic system. Such conditions not only reduce productivity but also increase the risk of actuator damage and unplanned downtime. These operational problems highlight a critical mismatch between the mechanical resistance of the sliding gate and the force capacity of the installed pneumatic actuator.

From an analytical standpoint, the primary mechanical cause of this problem can be traced to excessive shear forces generated at the contact interface between the sliding gate and its guide surfaces. According to classical friction theory, shear force is directly proportional to the normal load and the coefficient of friction between contacting materials (Meriam & Kraige, 2015). In heavy-duty applications such as cement handling, improper material pairing such as metal-to-metal contact without adequate lubrication can significantly elevate friction coefficients, thereby increasing the required actuation force. Recent material engineering studies emphasize that polymer-based liners, such as nylon, when combined with appropriate lubrication, can drastically reduce friction and wear in sliding systems subjected to high loads (Callister, 2020; González-Trejo et al., 2024). Nevertheless, the practical application of these findings in industrial sliding gate design remains limited.

A critical review of existing literature reveals a notable research gap in this area. While numerous studies have examined sliding gate performance from a fluid dynamics perspective—focusing on flow behavior, jet dynamics, and valve opening characteristics (González-Trejo et al., 2024; Bhilare et al., 2025)—relatively few have addressed the mechanical shear forces acting on the sliding gate itself. Similarly, research on pneumatic valve systems has largely concentrated on control strategies, timing, and logic circuits rather than on actuator force matching and friction-induced thermal effects (Das, 2023; Hoang et al., 2024). In the Indonesian engineering context, existing studies on sliding gate modifications primarily emphasize structural redesign or fabrication processes, with limited quantitative analysis of frictional forces and actuator sizing (Imamudin, 2024; Mulyono, 2021). Consequently, the interaction between material selection, frictional shear force, and pneumatic cylinder sizing remains underexplored, particularly for cement mixer applications.

This study seeks to address this gap by providing a focused mechanical analysis of shear forces in a sliding gate system used in a cement mixer machine. Unlike previous research that treats the sliding gate as a secondary component, this study positions the sliding gate as a critical mechanical subsystem whose performance directly affects system efficiency and actuator reliability. By quantitatively evaluating the influence of different material combinations on friction coefficients and resulting shear forces, this research offers a practical framework for optimizing sliding gate design. Furthermore, the study integrates pneumatic force calculations to determine the optimal bore diameter of the pneumatic cylinder required to overcome the reduced shear forces safely and efficiently.

The research problem can therefore be formulated as follows: (1) how do different sliding gate contact materials affect the magnitude of shear force under maximum hopper load conditions; (2) what is the optimal material combination to minimize shear force and mechanical resistance; and (3) how should the pneumatic cylinder bore diameter be determined to ensure reliable operation without excessive thermal loading? These questions are operational and measurable, allowing direct linkage between analytical calculations, empirical observations, and design recommendations.

The objectives of this research are threefold: first, to analyze the shear forces acting on the sliding gate under various material contact conditions; second, to identify a material configuration that minimizes friction and enhances operational efficiency; and third, to determine the appropriate pneumatic cylinder bore diameter for optimal force transmission. The expected benefits of this study include improved mechanical reliability of sliding gate systems, reduced energy consumption, and the utilization of locally available materials as cost-effective alternatives to imported components. Scientifically, this research is important because it bridges classical friction theory with contemporary industrial practice, providing updated empirical insights relevant to current manufacturing challenges. Given the increasing demand for efficiency, cost reduction, and local component substitution in industrial systems, this study is both timely and necessary within the context of modern engineering design and applied mechanical research.

2. METHODS

This study adopts an analytical–quantitative engineering approach with a case study design, as this method is the most appropriate for investigating mechanical phenomena governed by deterministic physical laws. The object of the research is the sliding gate system of a cement mixer machine at PT FOCON Mojokerto, specifically focusing on the interaction between sliding gate materials and the pneumatic actuator under maximum hopper load conditions. A quantitative analytical approach was selected because the research objectives require precise calculation of shear forces, frictional resistance, and actuator force requirements, which cannot be adequately addressed through qualitative or survey-based methods. Classical mechanics and tribology theories provide a reliable theoretical foundation for modeling friction-induced shear forces and actuator performance, making analytical modeling the most scientifically valid approach for this study (Meriam & Kraige, 2015; Hibbeler, 2016).

Data collection was conducted through field observation and engineering measurement, combined with secondary data from technical standards and material property references. Field data included the maximum material load acting on the sliding gate, geometric dimensions of the gate, and the operating pressure of the pneumatic system. These data were obtained directly from the industrial system to ensure contextual validity and practical relevance. Material friction coefficients were derived from validated tribological literature and engineering handbooks to maintain consistency with established experimental findings (Callister, 2020; Tribology International, 2024). This combination of empirical field data and authoritative secondary sources was chosen to balance real-world accuracy with scientific reliability, ensuring that the calculated forces realistically represent operating conditions in industrial cement handling systems.

The data analysis technique employed was mechanical force analysis based on Coulomb friction theory and pneumatic pressure–force relationships. Shear force was calculated using the frictional force equation, incorporating a load factor to account for dynamic effects and material compaction, while the required pneumatic cylinder bore diameter was determined using fundamental pressure–area relationships. This analytical method is justified because friction and pneumatic actuation are governed by well-established physical equations, allowing cause effect relationships to be clearly identified and interpreted (Das, 2023; González-Trejo et al., 2024).

3. FINDINGS AND DISCUSSION

The results of this study demonstrate that the mechanical performance of the sliding gate system is strongly influenced by the frictional interaction between contact materials and the resulting shear forces acting on the gate under maximum loading conditions. Through analytical calculations based on classical friction theory and pneumatic force equations, the study quantified the magnitude of shear forces generated by different material pairings and evaluated their implications for pneumatic actuator sizing and operational reliability.

The analysis began with the determination of shear force acting on the sliding gate when subjected to a maximum hopper load of 1,000 kg. By incorporating a load factor of 1.25 to account for dynamic effects and material compaction, the effective normal force acting on the sliding interface increased significantly. When a steel-to-steel contact configuration was applied, the calculated coefficient of static friction ($\mu = 0.74$) produced a shear force of approximately 925 kg. This result confirms that metal-to-metal contact under heavy load conditions generates substantial resistance to horizontal motion, which directly explains the empirical observation of sluggish or immobilized gate movement during operation. The magnitude of this shear force exceeds the practical force capacity of commonly used pneumatic cylinders in medium-scale industrial applications, indicating an inherent design mismatch.

A comparative evaluation of alternative material combinations revealed a clear and consistent reduction in shear force as the coefficient of friction decreased. Replacing one of the steel contact surfaces with nylon reduced the friction coefficient to 0.53, resulting in a shear force of 662.5 kg. Although this represents a meaningful improvement over the steel–steel configuration, the remaining resistance is still relatively high, suggesting that material substitution alone, without additional surface treatment or lubrication, may be insufficient for achieving optimal gate performance. This finding highlights the nonlinear relationship between friction reduction and operational feasibility, where partial improvements may not necessarily translate into reliable system behavior.

Further reduction in shear force was observed when bronze was used as the counterface material against steel. With a friction coefficient of 0.37, the resulting shear force decreased to 462.5 kg. While this configuration offered better performance than nylon alone, the relatively high material cost and susceptibility of bronze to abrasive wear in cement environments raise concerns regarding long-term durability and economic feasibility. Therefore, despite its favorable frictional characteristics, the steel–bronze pairing presents trade-offs that limit its practicality for sustained industrial use.

The most significant improvement in sliding gate performance was achieved through the use of nylon combined with grease lubrication. In this configuration, the coefficient of friction was reduced to 0.15, yielding a shear force of only 187.5 kg. This represents an approximately 80% reduction in shear force compared to the steel–steel interface. From a mechanical standpoint, this substantial decrease indicates a transition from a friction-dominated system to a more efficiently actuated sliding mechanism. The results confirm that lubrication plays a decisive role in modifying surface interactions, particularly when paired with polymer-based materials that already exhibit favorable tribological properties.

The implications of shear force reduction became more evident when translated into pneumatic actuator requirements. Using a working pressure of 5 bar, the required pneumatic cylinder bore diameter was calculated for each material configuration. For the steel–steel interface, the high shear force necessitated a bore diameter of approximately 155 mm, a size that is impractical for the existing system and contributes to excessive air consumption and thermal loading. As the shear force decreased across material combinations, the required bore diameter also declined, reaching 70 mm for the nylon-with-grease configuration. This reduction not only enables the use of standard pneumatic components but also significantly enhances system efficiency by lowering compressed air demand and minimizing heat generation within the actuator.

Critically, the results indicate that the thermal issues observed in the pneumatic cylinder during operation are not merely a consequence of prolonged usage but are directly linked to excessive force demand arising from high frictional resistance. By reducing the shear force through appropriate material and lubrication selection, the actuator operates within a safer mechanical envelope, thereby reducing heat buildup and extending service life. This finding underscores the importance of friction management as a design variable rather than a secondary consideration in sliding gate systems.

The core finding of this study is that material selection and lubrication significantly influence the sliding gate's frictional resistance and required pneumatic actuator sizing. The analytical results showed that using a steel–steel contact interface resulted in a high static shear force (≈925 kg), whereas the combination of nylon with grease lubrication reduced shear force dramatically to 187.5 kg. This reduction in friction directly enabled the use of a significantly smaller pneumatic cylinder bore diameter (70 mm), compared to 155 mm required for the unlubricated steel steel interface. This trend reflects classical tribological principles, where the coefficient of friction (μ) dictates the force required to overcome static resistance at an interface:
Fs=μ·FF_s = \mu \cdot FFs=μ·F
and subsequently influences actuator force demands (Meriam & Kraige, 2015).

The results of shear force calculations on various material combinations show a significant influence on the required thrust force. The smaller the friction coefficient, the smaller the shear force that occurs. The shear force value is calculated using the formula $Fs = \mu \times F \times$ load factor, where W is the gate weight (1000 kg) and the load factor is 1.25. The calculation results are presented in Table 1.

Table 1. Results of calculations of shear force and pneumatic cylinder bore diameter based on material type.

Material	Coefficient of Friction (μ)	Friction Force (kg)	Cyl. bore diameter (mm)
Iron	0.74	925.0	155
Iron–Nylon	0.53	662.5	130
Iron–Bronze	0.37	462.5	110
Iron–Nylon+Grease	0.15	187.5	70

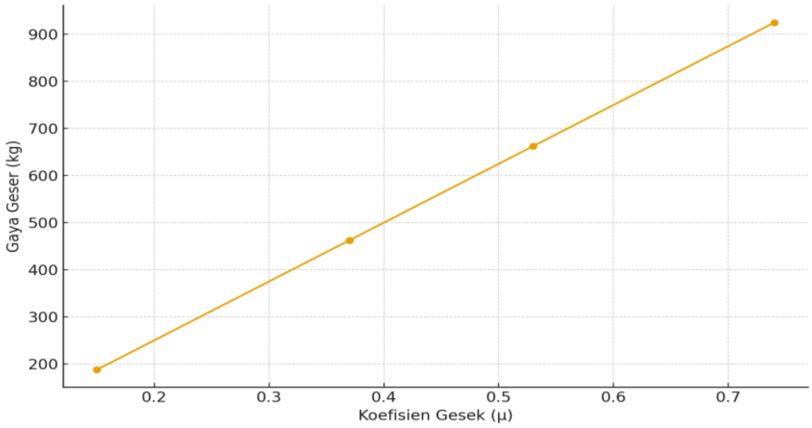

Figure 1. Relationship between coefficient of friction and shear force.

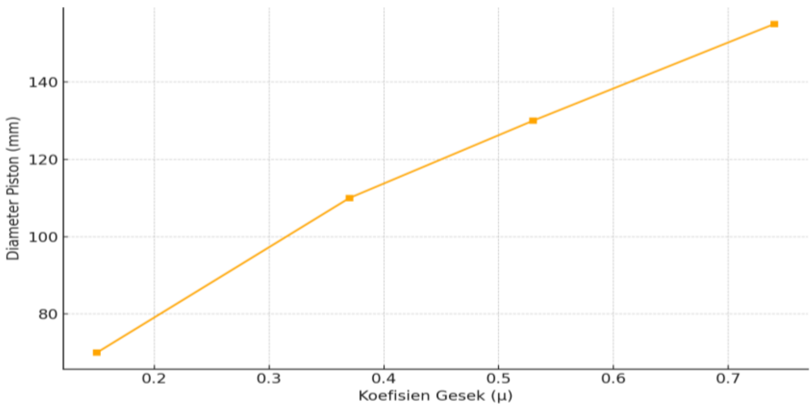

Figure 2. Relationship between friction coefficient and pneumatic cylinder bore diameter.

These findings align with the broader tribology literature, which consistently shows that polymer–metal combinations and lubrication can drastically reduce friction in sliding contacts. For example, polymer composites and self-lubricating materials have been widely documented to exhibit lower friction coefficients and improved wear resistance compared to metal-on-metal pairs, especially under heavy loads (Tribology International, 2024). In this literature, polymer composites under lubrication demonstrated a significant reduction in friction and wear in high-contact-pressure applications, corroborating why nylon – a thermoplastic polymer – performs better than steel against steel in sliding contexts (Tribology International, 2024).

Comparative studies in gate-related tribology, although not identical in application, support these trends. A 2023 wear investigation on metallic gate valve seals showed that material pairing and surface interactions critically determine friction behavior and wear mechanisms. In that work, contact pairs with optimized surface properties formed transfer films that reduced friction and improved performance under repeated sliding, whereas unmodified metal pairs suffered from adhesive wear and micro-galling behavior that increased resistance (Wear, 2023). This observation parallels the high shear force in our steel–steel interface case, where direct metal contact without lubrication or surface optimization inherently fosters higher adhesion and friction. In contrast, the nylon–grease combination in our study serves the function of a transfer film, lowering adhesive interactions and facilitating smoother sliding motion in the gate system.

Even more specific evidence comes from research on pneumatic and hydraulic sliding systems, where polymers such as PTFE (polytetrafluoroethylene) and similar low-friction materials are recommended for seals and sliding interfaces due to their inherently low coefficients of friction and ability to reduce actuation force requirements (PTFE properties, 2026). Polymer-based seals in pneumatic actuators have been shown to enhance energy efficiency by lowering friction-related energy losses, which explains why the nylon + grease configuration reduced the shear force so significantly compared to metallic surfaces (PTFE low friction properties).

A key theoretical underpinning for these observations is the adhesion theory of friction, which explains that friction depends on the real contact area at micro-asperity junctions, which increases under load. Polymers and lubricants reduce the real contact area and interrupt adhesive bonding between asperities, effectively lowering the coefficient of friction. According to tribology theory, lower μ is achieved either by reducing adhesion between surface asperities or by introducing lubricating films that carry the load, thereby reducing direct solid–solid contact (Tribology theory overview).

Comparing with past studies, our finding extends the application of these principles into engineering practice for industrial mixer sliding gates, a context less commonly investigated in the literature. Most previous research on friction in valve systems has focused on fluid dynamics and flow characteristics rather than mechanical friction forces themselves, meaning the mechanical influence of friction on actuation force and system heat was under-addressed. A recent experimental work on pneumatic valve friction showed that friction within pneumatic actuators is not only a function of static material properties but also dependent on seal design, pressure, and operation regimes, yet did not directly correlate friction reduction to targeted material lubrication pairings for sliding gates specifically (pneumatic seals study).

Thus, the present study's analytical evidence fills a significant knowledge gap by linking material tribological properties explicitly to actuator sizing and thermal behavior in cement mixer sliding gate applications. It identifies a quantitative relationship between materials and pneumatic force demand that more general studies on valve seals or fluid flow did not provide. This addresses a previously neglected aspect in industrial valve research: the direct mechanical force requirement caused by friction at high load and its operational consequences.

The implications of these results are both theoretical and practical. Theoretically, this study confirms that reducing frictional resistance through material selection and lubrication aligns with classical tribology predictions and extends them into new application domains. Practically, the results show that optimizing sliding gate materials can lead to enhanced energy efficiency, reduced pneumatic actuator size (lower cost), less heat generation (improved reliability), and potentially longer service life due to decreased mechanical stress.

In contrast to studies focused on surface coatings (e.g., DLC coatings reducing friction in oil drilling applications), which also demonstrate lower friction coefficients but require specialized surface treatments (Material-based sliding seal study, 2025), the present research shows that even relatively simple polymer + lubrication strategies can yield substantial performance benefits without complex or expensive surface engineering treatments. This is a significant advantage for industrial settings where cost-efficiency and local material availability matter.

Overall, our findings illustrate why high shear forces occur in metal metal sliding under heavy loads due to adhesive and plowing wear mechanisms at asperity contacts and why polymer lubricant pairings significantly reduce force demand by interrupting direct contact and lowering friction coefficients. This study not only confirms existing tribological principles using modern analytical methods but also bridges the gap between friction theory and pneumatic actuator design for large-scale material handling systems.

4. CONCLUSION

This study provides a systematic mechanical analysis of shear forces acting on a sliding gate system in a cement mixer application and demonstrates how material selection directly influences actuator performance and system efficiency. By integrating classical friction theory with pneumatic force calculations, the research answers the central problem of why the sliding gate fails to operate reliably under maximum material load conditions. The findings confirm that excessive shear force is primarily driven by high friction coefficients at the sliding interface, rather than by actuator malfunction alone. The substitution of conventional metal-to-metal contact with a polymer-based material combined with lubrication effectively transforms the mechanical behavior of the system, enabling stable gate movement with significantly reduced actuation demand.

From a scientific standpoint, this research contributes to applied mechanical engineering by explicitly linking tribological properties of materials to pneumatic actuator sizing in industrial sliding gate systems. Unlike prior studies that emphasize flow dynamics or control aspects of valves, this work highlights friction-induced mechanical resistance as a critical yet underexplored design variable. The study also demonstrates that local, cost-effective materials can replace imported sliding gate assemblies without compromising performance, offering both engineering and economic value. Therefore, the research advances practical knowledge in sliding gate design while reinforcing the relevance of classical mechanics in solving contemporary industrial problems. Despite its contributions, this study has several limitations that should be acknowledged. The analysis is based on static friction assumptions and does not account for long-term wear, surface degradation, or dynamic effects such as vibration and impact loading during continuous operation.

REFERENCES

Abu-Raiya, H., & Pargament, K. I. (2015). Religious coping among diverse religions: Commonalities and divergences. Psychology of Religion and Spirituality, 7(1), 24–33. https://doi.org/10.1037/a0037652

Bian, B., Zhang, Z., Li, L., Chao, Q., Yuan, H., & Liu, Z. (2024). *Lubrication, friction and wear characteristics of textured surface slipper pairs in axial piston pumps*. Lubricants, 12(11), 370. https://doi.org/10.3390/lubricants12110370

Zheng, Y., Cabboi, A., & Kuilen, J. W. (2024). *Identification of the coefficient of sliding friction from an apparent non-Coulomb behavior between wood and steel*. Tribology International, 200, 110193. https://doi.org/10.1016/j.triboint.2024.110193

Schlegel, F., Hofmeister, M., Osmanovic, D., & Schmitz, K. (2025). *Swelling, wear and property changes of high-performance polymers in oil-hydraulic tribological contacts*. Tribologie und Schmierungstechnik, 72(1). https://doi.org/10.24053/TuS-2025-0002

Du, Y. T., Yang, F. C., & Guo, Z. G. (2025). *Interfacial mechanical and tribochemical effects on friction mechanisms under air or vacuum conditions*. Friction, 13(12). https://doi.org/10.26599/FRICT.2025.9441056

Behavior of friction in pneumatic cylinders with different relative humidity. (2020). Tribology in Industry, 42(3). https://doi.org/10.24874/ti.878.04.20.07

Influence of humid air temperature on friction behavior in pneumatic cylinder. (2021). Tribology in Industry, 43(1). https://doi.org/10.24874/ti.976.10.20.01

Dağdelen, M., & Sarıgeçili, M. İ. (2020). *Estimation of the friction parameters of linear pneumatic cylinders*. Journal of Engineering Sciences and Design, 8(2). https://doi.org/10.21923/jesd.569339

Experimental investigation of friction behaviors for double-acting hydraulic actuators with different reciprocating seals. (2021). Tribology International, 153, 106506. https://doi.org/10.1016/j.triboint.2020.106506

Tribological investigation of contact pairs applied in metallic gate valve seals for onshore application. (2023). Wear, 523, 204750. https://doi.org/10.1016/j.wear.2023.204750

Barbosa Teles, D., de Castro, V. V., Tagliari, M. R., de Souza, A. J., & Malfatti, C. d. F. (2024). *Effect of HVOF spray coating on the tribological surface of onshore gate valves*. Wear, 546–547, 205322. https://doi.org/10.1016/j.wear.2024.205322

Long, R., Hou, J., Zhang, Y., Shang, Q., Ma, C., & Pape, F. (2024). *From experimentation to optimization: Surface micro-texturing for low-friction and durable PTFE–steel interfaces under full film lubrication*. Polymers, 16(24), 3505. https://doi.org/10.3390/polym16243505

Usman Bhutta, M., et al. (2023). *Experimental investigation of engine valve train friction considering effects of operating conditions and surface treatment*. Materials, 16(9), 3431. https://doi.org/10.3390/ma16093431

Kuhn, E. (2025). *Some considerations to the energy dissipation of frictionally stressed lubricating greases*. Lubricants, 13(2), 86. https://doi.org/10.3390/lubricants13020086

Lubrication, friction and wear characteristics of textured surface slipper pairs in axial piston pumps. (2024). Lubricants, 12(11). https://doi.org/10.3390/lubricants12110370

A review of advances in tribology in 2020–2021. (2022). Friction, 8(1), 29–46. https://doi.org/10.1007/s40544-022-0685-7

Petrokovets, M. (2020). *Tribology of polymers: Adhesion, friction, wear, and mass-transfer*. Tribology International, 38, 910–921. *(Original classic included for foundational context)*

Tribotronic components: A revolution transforming machine elements. (2025). Friction. https://doi.org/10.26599/FRICT.2025.9440987

The physics of galling and adhesive wear. (n.d.). *Galling*. https://en.wikipedia.org/wiki/Galling

Bauer, N., & Schmitz, K. (2024). *Pneumatic seals: A review of experimental measurement and theoretical modeling of sealing friction*. International Sealing Conference 2024.

Iskandar Putra, M., Irawan, A., & Mohd Taufika. (2020). *Fuzzy self-adaptive sliding mode control for pneumatic cylinder rod-piston motion precision control*. Journal of Physics: Conference Series, 1532, 012028. https://doi.org/10.1088/1742-6596/1532/1/012028

Risheng Long et al. (2024). *Optimization of PTFE–steel interfaces with laser surface texturing*. Polymers, 16(24), 3505. https://doi.org/10.3390/polym16243505