

Design and Fabrication of a Low-Cost Mini Pin-on-Disc Tribology Machine for TVET Applications

A.A.M. Redhwan^{1*}, O.W. Zulkarnain¹, K. Ali¹, A.J. Mohamad¹, A.R.M. Aminullah¹, M.M.A. Faris¹,
A.Z.M Sharif², A.I. Ramadhan³.

¹ Faculty of Engineering Technology, TATI University College, Kampus Teluk Kalong, 24000 Kemaman, Terengganu, Malaysia

² Fakulti Teknologi dan Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, 76100, Hang Tuah 6 Jaya, Durian Tunggal, Melaka, Malaysia

³ Department of Mechanical Engineering, Universitas Muhammadiyah Jakarta, Jakarta, 10510, Indonesia

*Corresponding author E-mail: redhwan@uctati.edu.my

Abstract

This paper presents the design, fabrication, and performance evaluation of a compact and cost-effective Mini Pin-on-Disc Tribology Machine, developed to support tribological education and research in Technical and Vocational Education and Training (TVET) institutions. Commercial tribometers, while precise, are often prohibitively expensive and technically complex for classroom implementation. To address this gap, a novel machine was designed with a vertical disc and horizontal pin orientation to enhance debris removal during testing, thereby increasing measurement reliability. Components were modeled using Autodesk Inventor 2021 and fabricated using lathe and milling machines, with stainless steel and aluminum alloy AL319 are used for the base and disc, respectively. A DC motor provided consistent rotational motion, while sensors and Arduino interfaces enabled real-time data acquisition. Experimental tests using a high-speed steel (HSS) pin demonstrated that wear rate and coefficient of friction increased with higher loads and extended durations, confirming expected tribological behavior. The machine performed reliably across all tests, offering repeatable and accurate results. With its modular construction, digital instrumentation, and low cost, this device is highly suitable for hands-on training in tribology, promoting skill development and engineering innovation in TVET environments.

Key Words: Pin on Disc, Mini Tribology Machine, High Speed Steel, AL 319 Aluminium Alloy, Wear Rate, CoF

1.0 Introduction

Tribology, derived from the Greek word *tribos* meaning "rubbing", is the interdisciplinary science and engineering of interacting surfaces in relative motion (Sasaki, 2023). It encompasses the study of friction, wear, and lubrication — phenomena that are critically important in mechanical systems ranging from simple household tools to complex industrial machinery (Meng et al., 2020). The quantification and analysis of these phenomena are essential in optimizing machine performance, reducing energy consumption, and enhancing the durability of engineering components (Samylingam et al., 2024). In educational settings, especially within technical and vocational institutions, understanding tribological principles forms the basis for competencies in machining, maintenance, and materials engineering (Mang et al., 2011).

One of the most established methods for investigating tribological behaviour is the Pin-on-Disc (PoD) technique (Verma et al., 2022). In this method, a pin is pressed against a rotating disc under a controlled load to simulate surface interactions and measure wear and friction (Kennedy et al., 2015). Commercial tribometers utilizing this method are typically sophisticated and expensive, often inaccessible to educational institutions with limited funding. Additionally, traditional PoD tribometers may suffer from experimental inaccuracies due to specimen debris accumulating at the contact interface, which compromises the validity of the results (Sadeghi et al., 2024). This highlights a dual challenge: the need for cost-effective and accurate tribological instrumentation tailored for educational purposes.

To bridge this gap, this study presents the design, fabrication, and performance evaluation of a miniaturized, low-cost Pin-on-Disc (PoD) Tribology Machine. The PoD setup is widely accepted for evaluating tribological behavior due to its simplicity and reliability (Verma et al., 2022). The design incorporates practical improvements, such as a revised pin and disc orientation to allow gravity-assisted debris removal, and digital sensors for accurate

measurement. The objectives of this paper are to describe the design methodology, present the fabrication process, and analyze the machine's performance through experiments evaluating wear rate and coefficient of friction under varying loads and durations.

2.0 Methodology

The methodology section is divided into three stages namely design, fabrication and assembly, and run test.

2.1 Designing of Pin on Disc Tribology Machine

The design process for the Pin-on-Disc Mini Tribology Machine began with identifying the limitations of existing tribometers, particularly their high cost, complexity, and susceptibility to debris accumulation during testing. These shortcomings led to the conceptualization of a redesigned machine that would be simpler to use, easier to fabricate, and more suitable for hands-on learning in a TVET setting. The key design innovation was the repositioning of the pin and disc — where the specimen disc is oriented vertically and the pin is placed horizontally. This gravity-assisted orientation allows loose wear debris to fall away from the contact zone, reducing contamination and improving the accuracy of wear and friction measurements.

The conceptual design was sketched manually and then modeled using Autodesk Inventor 2021. Detailed 2D and 3D models of each component were created to ensure dimensional accuracy and proper fit during assembly. The machine structure was designed to be modular, with replaceable components for easy maintenance and customization. The main frame was constructed from stainless steel for its corrosion resistance, rigidity, and aesthetic finish. Figure 1(a) depicts the conceptual design sketch by hand, while Figure 1(b) depicts the detail 2D design modelled with Autodesk Inventor 2021

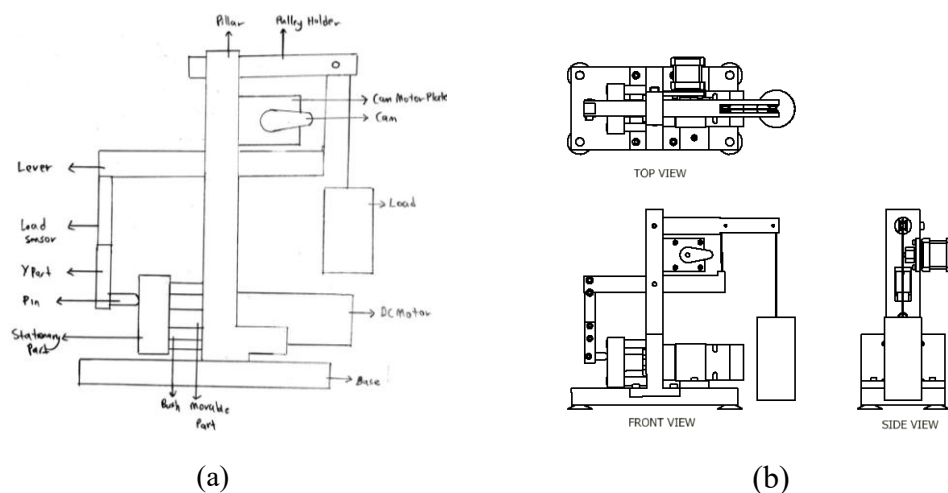


Figure 1: The design steps with (a) Conceptual design in manual sketch (b) Detail two design modelled using Autodesk Inventor 2021.

The mechanical assembly includes critical components such as the rotating disc mount, pin holder, loading lever, and camshaft. The motion system employed a DC motor to rotate the specimen disc at a fixed speed, while a stepper motor was integrated to control the camshaft that governs the pin-disc contact timing. The use of sensors, including a load cell (for measuring applied force) and a tachometer (for rotational speed monitoring), ensured reliable data acquisition during experiments.

2.2 Fabrication and Assembly of Pin on Disc Tribology Machine

The fabrication stage was conducted using workshop machinery including lathe machines, milling machines, and hand tools. Components with cylindrical geometry, such as the bushings, camshaft, and pin, were machined using a lathe, while flat and angular parts like the base plate, lever, and motor mounts were fabricated using milling operations. Each fabricated part underwent finishing processes such as deburring, tapping, and surface filing to meet the dimensional tolerances specified in the CAD drawings. The individual components were then assembled following a systematic approach to ensure alignment and structural stability. Electrical wiring for sensors and motor drivers was carried out in parallel, with Arduino software used to calibrate and interpret sensor outputs.

2.3 Test Run of Pin on Disc Tribology Machine

Once assembled, the machine was tested for functionality, and troubleshooting was performed to correct any mechanical misalignments or sensor inaccuracies. The test run was conducted to determine the coefficient of friction and wear rate of the specimen AL319 alloy in meantime to determine the functionality of the new fabricated tribometer. Two input parameters namely time in the range of 3 to 6 minutes and loads which in the range of 400 to 1600g are used in this test. While the rotation speed of disc kept constant at 1000 rpm. Table 1 tabulated the input parameters.

Table 1: Input Parameters of the test

Parameter	Low	High.
Time (min)	3	6
Load (g)	400	1600
Rotation (rpm)	1000	1000

While two output parameters namely wear rate and coefficient of friction (CoF) are used as output parameters. The method used to determine the wear rate is by weight equation (Yang, 2003). By using this equation, the wear rate is determined with respect to time and the unit of wear rate is mm/sec. The wear rate equation is given by equation (1).

$$w. r. w = (w_1 - w_2) \times t \div w_1 \quad (1)$$

Where: w_1 is the weight of aluminium sample before friction action, w_2 is the weight of aluminium sample after friction action and t is the test time (3 min, 6 mins.).

The coefficient of friction (μ) is calculated by the ratio of the frictional force to the loading force on the pin (Yoon et al., 1997). The method used to find the coefficient of friction is using its formula which is show in equation (2):

$$\mu = F/N \quad (2)$$

Where: F is frictional force and N is the normal force. Both F and N are measured in units of force (such as newtons or pounds), the coefficient of friction is dimensionless. The coefficient of friction has different values for static friction and kinetic friction.

The experiment was conducted in accordance to flow chart as shown in Figure 2. Initially, each specimen was weighed using an analytical balance with an accuracy of four decimal places (grams). The initial surface condition of each specimen was then recorded using a digital microscope and documented in a table. Subsequently, the pin and specimen were

mounted on the tribometer using an Allen key. The machine was run at a constant speed of 1000 rpm for two sets of tests. In the first set, four specimens were tested for 3 minutes under loads of 400 g, 800 g, 1200 g, and 1600 g. In the second set, another four specimens were tested for 6 minutes under the same load conditions. After each test, the final weight of the specimens was measured and recorded. Their final surface conditions were also captured using the digital microscope. A comparison between the initial and final surfaces was conducted. All data were compiled in a table for analysis, and conclusions were drawn based on the observed results.

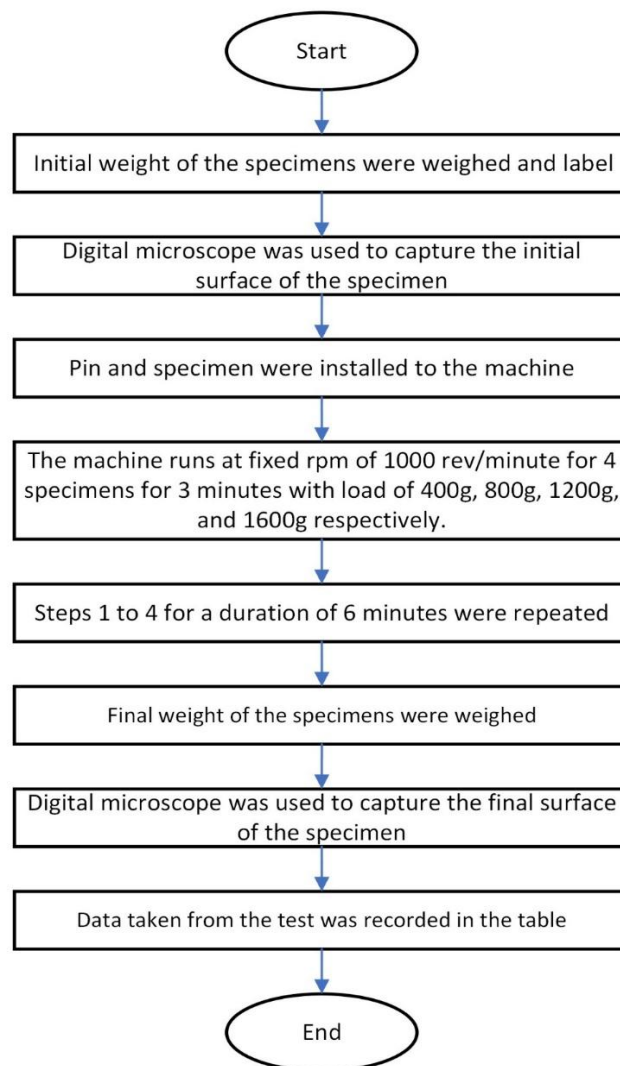


Figure 2: The flow process of the test.

3.0 Result and Discussion

This section is separated into three sections which discuss the design, fabrication and test run of the machine. The final result represents a fully functional tribology machine capable of generating reproducible wear and friction data, while serving as a hands-on learning platform for students

3.1 Detail design of Pin on Disc Tribology Machine

The detail design of the Pin-on-Disc Mini Tribology Machine successfully addressed the primary concerns identified in the problem statement. The vertical disc and horizontal pin

orientation enabled gravitational removal of wear debris from the sliding interface, minimizing measurement interference and improving accuracy. Each component was meticulously modeled using Autodesk Inventor 2021, allowing accurate visualization and dimensional planning before fabrication. The modular structure of the machine facilitated easy assembly, maintenance, and part replacement — all important features for use in an educational environment. Furthermore, the integration of a DC motor for disc rotation and a stepper motor for camshaft control enabled smooth operation during testing. Digital load sensing and rotational speed monitoring, through Arduino and tachometer systems respectively, ensured precise and repeatable data acquisition. The final 3D design of Pin on Disc Tribology Machine is depicted in Figure 3. While the detail parts are tabulated in Table 2.

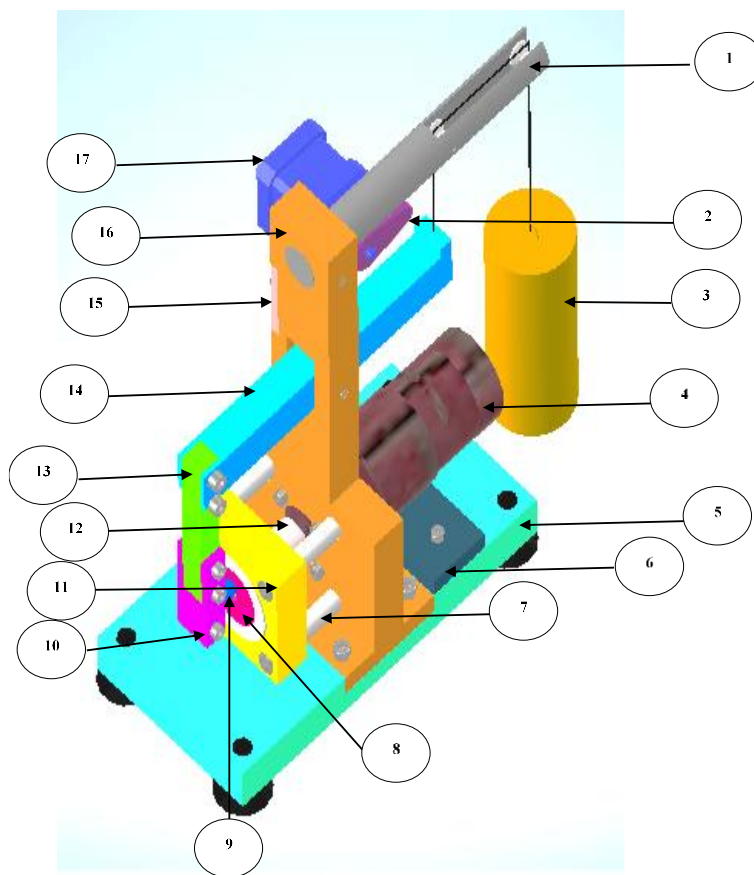


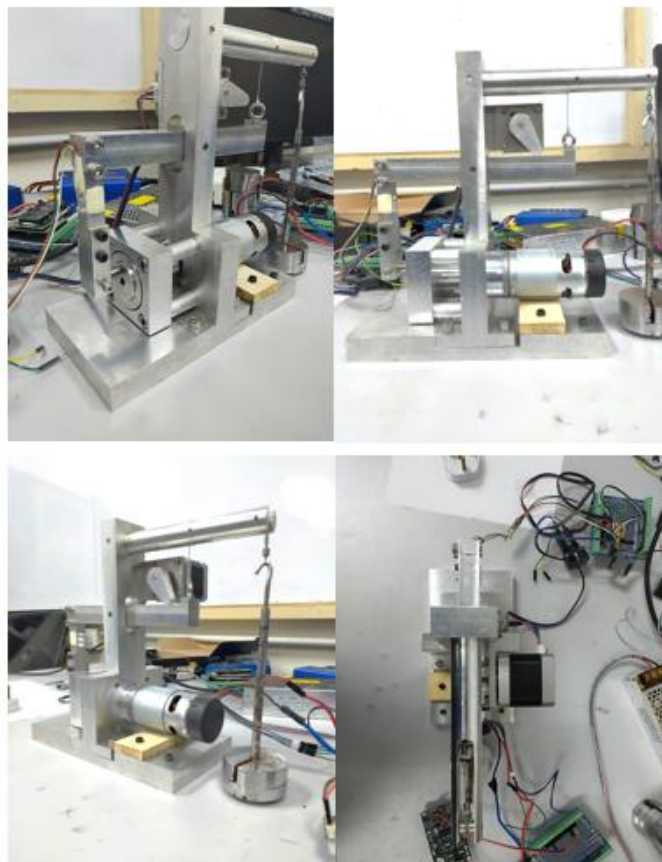
Figure 3: 3D modelled design with parts labelled.

Table 2: Part of the machine components

Parts No.	Component	Parts No.	Component
1	Pulley Holder	10	Pin Holder
2	Camshaft	11	Stationary part
3	Load	12	Movable Part
4	DC Motor	13	Load Sensor
5	Base	14	Lever
6	DC Motor Retainer	15	Camshaft motor Plate
7	Bush	16	Pillar
8	Specimen	17	Stepper Motor
9	Pin		

3.2 Fabrication of Pin on Disc Tribology Machine

The fabrication process involved extensive use of both lathe and milling machines, alongside hand tools such as files, taps, and calipers. Cylindrical components such as the pin, bushings, and pulleys were turned on the lathe, while flat parts including the base, camshaft motor plate, and pin holder were milled from stainless steel blocks. One notable aspect of the fabrication work was the high attention to dimensional accuracy and surface finish, essential for ensuring mechanical compatibility and smooth motion. Several finishing processes — including chamfering, counterboring, deburring, and tapping — were carried out to improve part fitment and ease of assembly. Fasteners such as M4 and M5 bolts were used to assemble the structural frame, while deep groove ball bearings were incorporated to reduce friction in rotating elements. Figure 4 depicted the fabricated and assembled of the machine.

**Figure 4:** Fabricated and assembled of the machine

Despite thorough design and preparation, the assembly process revealed several practical challenges. The initial design of the pillar base lacked sufficient width and stability, leading to structural imbalance. This was resolved by redesigning and enlarging the base plate to ensure a stable foundation. Another issue was the potential collision between the load and DC motor due to their close vertical alignment. This was mitigated by extending the pulley holder to reposition the load path and avoid interference. Additionally, the stepper motor intended to control the camshaft lacked sufficient torque to resist the downward force from the load. As a temporary solution, manual intervention was used to control the pin-specimen contact timing; however, future iterations may require a higher-torque motor or a geared mechanism. Load sensor calibration was also a critical phase, where multiple trial runs were conducted to confirm that the applied load was accurately measured and transmitted to the pin-specimen interface.

3.3 Test run of Pin on Disc Tribology Machine

The running test results validated the functionality of the machine and confirmed its ability to generate consistent tribological data. Tests were performed at four different load conditions (400g, 800g, 1200g, and 1600g) and two-time durations (3 and 6 min) with a fixed disc rotation speed of 1000 RPM. Table 3 tabulated the result for wear rate while Table 4 tabulated the result for CoF. While the surface analysis aluminium specimen is depicted in Figure 5.

Table 3: The wear rate of the test run

Parameter	Specimen							
	A ₁	A ₂	B ₁	B ₂	C ₁	C ₂	D ₁	D ₂
Load (g)	400	400	800	800	1200	1200	1600	1600
Time (min)	3	6	3	6	3	6	3	6
Wear rate (mm/s)	0.2048	0.7422	0.3578	0.7677	0.4443	0.9581	0.8057	2.4557

Table 4: The CoF of the test run

Parameter	Specimen							
	A ₁	A ₂	B ₁	B ₂	C ₁	C ₂	D ₁	D ₂
Load (g)	400	400	800	800	1200	1200	1600	1600
Time (min)	3	6	3	6	3	6	3	6
CoF	0.912	0.9316	1.0005	1.0078	1.0169	1.0264	1.0201	1.0581

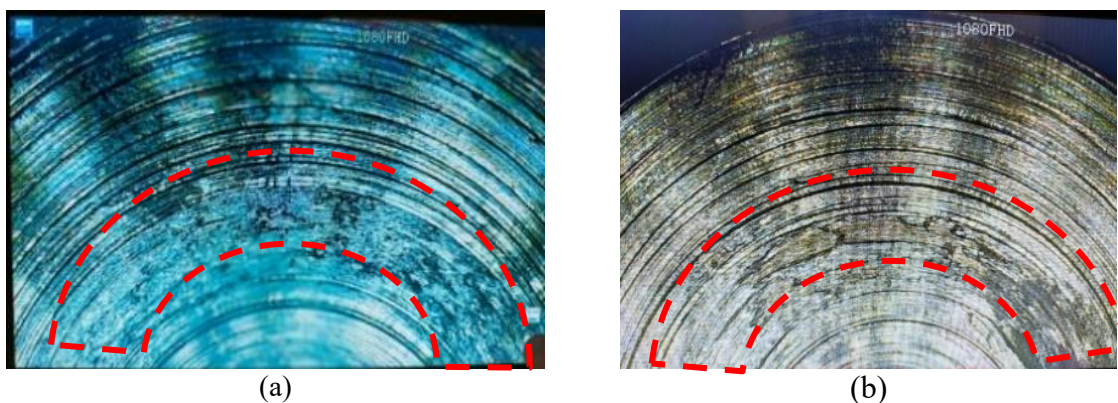


Figure 5. Surface analysis of (a) Specimen A₁ (b) Specimen D₂

Results showed that both wear rate and coefficient of friction (CoF) increased with higher loads and longer test durations. For example, the wear rate under a 1600g load increased

from 0.8057 mm/s at 3 min. to 2.4557 mm/s at 6 min, indicating a linear relationship between material loss and exposure time. Similarly, the CoF increased from 1.0201 to 1.0581 under the same conditions, suggesting greater resistance at the contact interface due to increased deformation and heat generation. The surface analysis of the aluminum specimens confirmed increased material removal and surface roughness with increasing load and test time. These outcomes aligned well with theoretical tribological behavior and affirmed the machine's capability to replicate real-world wear phenomena.

Overall, the successful design, fabrication, and testing of the mini tribology machine demonstrate its potential as both a practical educational tool and a basic research apparatus. It enables TVET students to gain hands-on experience with mechanical testing, data analysis, and problem-solving in a realistic lab environment, thereby aligning with competency-based training objectives.

4.0 Conclusion and Recommendation

The development of the Mini Pin-on-Disc Tribology Machine has demonstrated a successful integration of fundamental engineering design principles with practical fabrication methods tailored for technical education settings. The machine was thoughtfully conceptualized, designed using advanced CAD software, and fabricated using accessible workshop equipment. Key innovations, such as the vertical orientation of the disc and horizontal positioning of the pin, addressed the core issue of debris interference during testing, leading to more reliable and accurate tribological measurements. The incorporation of sensors and Arduino-based data acquisition systems further enhanced the machine's functionality, offering an interactive learning experience for students in mechanical and manufacturing programs. Most importantly, the machine fulfilled its objectives: it provided accurate measurement of wear rate and coefficient of friction while maintaining simplicity, cost-effectiveness, and educational value.

In terms of recommendation, future work may focus on optimizing motor control for automated operation, including the replacement of the current stepper motor with a higher torque model to support consistent camshaft positioning. Additional improvements could involve the integration of real-time data logging and graphical interfaces to facilitate more advanced analysis and remote learning. The machine could also be adapted for testing different material pairs and environmental conditions, such as lubrication or temperature variations. Overall, the project serves as a strong foundation for expanding tribology education within TVET institutions, supporting the vision of producing competent, hands-on graduates who are industry-ready. Institutions with limited access to commercial equipment now have a viable alternative that not only meets academic requirements but also promotes innovation and self-reliance in engineering education.

Acknowledgment

This research was not funded by any grant.

References

- Kennedy, F. E., Lu, Y., & Baker, I. (2015). Contact temperatures and their influence on wear during pin-on-disk tribotesting. *Tribology International*. <https://doi.org/10.1016/j.triboint.2013.10.022>
- Mang, T., Bobzin, K., & Bartels, T. (2011). *Industrial Tribology: Tribosystems, Friction Wear and Surface Engineering*. In Wiley - VCH.
- Meng, Y., Xu, J., Jin, Z., Prakash, B., & Hu, Y. (2020). A review of recent advances in tribology. In *Friction*. <https://doi.org/10.1007/s40544-020-0367-2>
- Sadeghi, B., Cavaliere, P., Shabani, A., Pruncu, C. I., & Lamberti, L. (2024). Nano-scale wear: A critical review on its measuring methods and parameters affecting nano-tribology. In *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*. <https://doi.org/10.1177/13506501231207525>
- Samylingam, L., Aslfattahi, N., Kok, C. K., Kadirgama, K., Sazali, N., Liew, K. W., Schmirler, M., Ramasamy, D., Harun, W. S. W., Samykano, M., Veerendra, A. S., Semin, & Sivaraos, S. (2024). Enhancing Lubrication Efficiency and Wear Resistance in Mechanical Systems through the Application of Nanofluids: A Comprehensive Review. *Journal of Advanced Research in Micro and Nano Engineering*. <https://doi.org/10.37934/armne.16.1.118>
- Sasaki, S. (2023). Advances in Tribology Driven by Surface Science. *E-Journal of Surface Science and Nanotechnology*. <https://doi.org/10.1380/ejssnt.2023-036>
- Verma, J., Nagdeve, L., & Kumar, H. (2022). Tribological investigations into pin-on-disc tribometer under dry sliding conditions at various temperature ranges. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*. <https://doi.org/10.1177/09544089211042954>
- Yang, L. J. (2003). Wear coefficient equation for aluminium-based matrix composites against steel disc. *Wear*. [https://doi.org/10.1016/S0043-1648\(03\)00191-1](https://doi.org/10.1016/S0043-1648(03)00191-1)
- Yoon, E. S., Kong, H., Kwon, O. K., & Oh, J. E. (1997). Evaluation of frictional characteristics for a pin-on-disk apparatus with different dynamic parameters. *Wear*. [https://doi.org/10.1016/S0043-1648\(96\)07365-6](https://doi.org/10.1016/S0043-1648(96)07365-6)