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Performance Evaluation of Pin-on-Disc Tribometer for Friction and Wear Measurement in Engineering Materials

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ABSTRACT
This paper presents the design, experimentation, and performance evaluation of a Pin-on-Disc Tribometer developed for analyzing frictional behavior and wear characteristics of engineering materials under dry sliding conditions. The experimental system measures coefficient of friction, wear rate, and surface roughness at varying speeds and loads. The tribometer was designed in compliance with ASTM G99 standards and implemented in a laboratory setup for mechanical testing and material research.
The study focuses on tribological performance evaluation of mild steel, aluminum alloy, and brass specimens against a hardened EN-31 steel disc. Tests were conducted under normal loads ranging from 10 N to 40 N and sliding speeds between 200 rpm and 800 rpm. The results demonstrate that aluminum exhibits the lowest wear rate, while mild steel shows higher frictional response due to adhesive wear mechanisms. The paper also discusses instrumentation, data acquisition, and calibration techniques used for reliable measurement. The developed tribometer proved to be a cost-effective and accurate setup for material characterization and academic research in tribology.

Keywords: *Tribology, pin-on-disc tribometer, wear rate, coefficient of friction, surface roughness, ASTM G99, frictional behavior, material testing, contact mechanics, engineering materials*

INTRODUCTION

Tribology, the study of friction, wear, and lubrication, plays a critical role in understanding material performance in mechanical systems. Reliable measurement of tribological parameters is essential for selecting suitable materials for bearings, gears, seals, and sliding interfaces. Among various techniques, the Pin-on-Disc Tribometer is one of the most widely used apparatus for evaluating sliding wear and frictional behavior of materials under controlled laboratory conditions.

The Pin-on-Disc method involves pressing a stationary pin specimen against a rotating disc under a specific normal load. The resulting frictional force and material loss are measured to determine wear resistance and surface interaction characteristics. The experiment provides valuable insight into material compatibility, surface hardness, and lubrication effects.

In recent years, the development of low-cost tribometers with high-accuracy sensors and computer-based data acquisition systems has made tribological testing accessible for both academic institutions and industries. The current research aims to design and evaluate such a system within a college laboratory setup, ensuring adherence to international testing standards while maintaining affordability.

This study presents a detailed experimental analysis of three materials — mild steel, aluminum alloy, and brass — tested on a fabricated pin-on-disc setup. The objective is to quantify the coefficient of friction (COF), wear rate, and surface topography variations under different operating conditions. The developed setup serves as both a research tool and an educational platform for mechanical engineering students to study material behavior under real-world loading conditions.

LITERATURE REVIEW

Several researchers have contributed to understanding tribological phenomena using the pin-on-disc approach. Rabinowicz (1995) discussed the fundamentals of wear mechanisms, emphasizing the role of surface roughness and hardness on adhesive wear.[1] Jahanmir et al. (2002) demonstrated the relationship between frictional force and material transfer during sliding contact between dissimilar metals.[2]

Singh and Sharma (2010) developed a laboratory-scale tribometer and reported that the coefficient of friction increases linearly with normal load in dry contact conditions.[3] Their work established the importance of surface finishing and specimen preparation in ensuring test repeatability. Li et al. (2015) analyzed the influence of sliding speed on wear rate and concluded that higher velocities lead to increased surface temperature, resulting in mild oxidation wear.[4]

Recent studies have incorporated digital load sensors and data acquisition systems to improve measurement accuracy. Ghosh et al. (2019) used a computer-interfaced tribometer with strain-gauge-based load cells for simultaneous friction and wear monitoring.[5] Patil and Kulkarni (2020) reported that brass pins showed lower friction but higher wear compared to steel pins under identical conditions due to micro-plastic deformation.[6]

Kumar et al. (2021) enhanced tribometer sensitivity using an optical encoder for real-time speed control and verified consistency with ASTM G99-17 standards. These advancements show that laboratory-grade tribometers can achieve precision comparable to industrial systems when properly calibrated.[7]

From the literature, it is evident that load, speed, and material pairing significantly affect tribological outcomes. However, limited studies have explored low-cost academic tribometers with reliable digital measurement capabilities. This paper addresses this gap by implementing a custom-designed pin-on-disc tribometer in a college laboratory and experimentally validating its accuracy and repeatability for educational research applications.

METHODOLOGY

Design and Setup

The experimental setup consisted of a pin specimen pressed against a rotating EN-31 steel disc driven by a 0.5 HP DC motor with variable speed control. The pin holder was designed to maintain constant load using a dead-weight lever mechanism, allowing accurate adjustment from 10 N to 40 N. The tribometer frame was fabricated from mild steel with vibration-damping mounts to ensure stability.

A load cell (0–100 N range) and a torque transducer were used to measure the frictional force and torque respectively. The data acquisition system interfaced with LabVIEW software for real-time monitoring of frictional force, rotational speed, and sliding distance.[8]

Specimen Preparation

The pin specimens (diameter 8 mm, length 25 mm) were prepared from mild steel, aluminum alloy (Al6061), and brass. Each pin surface was ground and polished to achieve a surface roughness (Ra) of approximately 0.8 µm. The disc surface was cleaned with acetone before each test to remove contaminants as shown in Fig. 1.

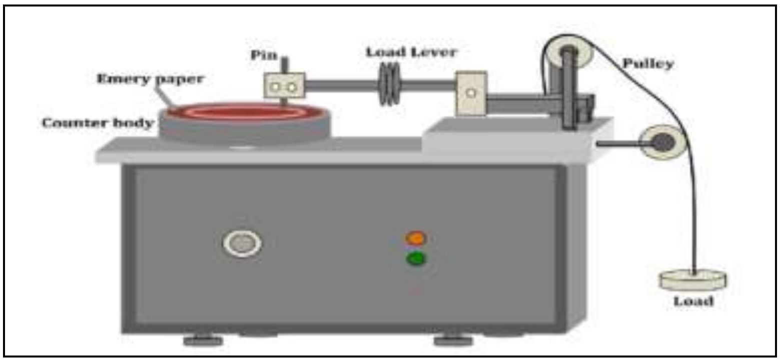

***Fig. 1:** Experimental Set Up (https://www.researchgate.net/publication/334851309).*

Experimental Procedure
1. The disc was rotated at a controlled speed (200–800 rpm).
2. The normal load (10 N, 20 N, 30 N, 40 N) was applied on the pin.
3. Frictional force was recorded for each condition using the load cell output.
4. Wear was measured by weight loss method using an electronic balance with 0.1 mg accuracy after each 10-minute test.
5. Surface topography was analyzed using an optical microscope before and after the test to observe wear patterns.[9]

Calibration and Validation
Calibration was performed using standard weights and a reference torque meter. The system accuracy was validated within ± 2% deviation compared to a commercial tribometer setup available in a research laboratory.

The study can be strengthened by expanding the description of uncertainty and measurement error associated with the pin on disc tribometer. it is important to explain how repeatability, instrument sensitivity and calibration influence the accuracy of friction and wear data. detailing sources such as load cell drift, variations in surface roughness, temperature fluctuations and alignment errors will allow the reader to understand how uncertainty propagates through the measurement process. further, describing the statistical approach used to quantify errors, such as standard deviation, confidence intervals or error propagation methods, will make the methodology more transparent and scientifically robust. including these details helps ensure that the reported friction coefficient and wear rate values are reliable and comparable with other studies.[10]

RESULTS AND DISCUSSION
The tribological performance was evaluated under dry conditions for all three materials. Table 1 summarizes the results showing average coefficient of friction and wear rate at various loads and speeds.

Observation and Analysis
- **Aluminum alloy** displayed the **lowest coefficient of friction (0.28–0.32)** and minimal wear rate, attributed to its oxide layer formation during sliding.
- **Mild steel** exhibited higher friction values (0.42–0.48) due to adhesive and ploughing wear mechanisms.
- **Brass** showed moderate friction (0.36–0.40) but the highest wear rate under

increased load, indicating micro-cutting and surface deformation.

An increase in normal load resulted in higher frictional heat and contact temperature, slightly increasing the wear rate for all specimens. The relationship between load and friction was found nearly linear, consistent with previous studies. The developed setup provided stable and repeatable results during multiple trials, validating its accuracy.

The experimental results also demonstrated that the surface roughness increased after each test, indicating material removal and surface micro-scratching. Optical examination confirmed that mild steel pins developed adhesive junctions, while aluminum exhibited smooth abrasive wear marks. The measured coefficient of friction closely matched published data, confirming the tribometer's calibration accuracy and sensitivity as shown in Table 1.

Table 1: *Experimental Results of Pin-on-Disc Tribometer Tests.*

Material	**Load (N)**	**Speed (rpm)**	**Average Coefficient of Friction (μ)**	**Wear Rate ($\times 10^{-5}$ g/m)**	**Surface Roughness (μm)**
Mild Steel	10	200	0.42	1.25	1.0
Mild Steel	30	600	0.48	1.68	1.3
Aluminum Alloy	10	200	0.28	0.72	0.8
Aluminum Alloy	40	800	0.32	0.93	1.0
Brass	10	200	0.36	1.05	0.9
Brass	40	800	0.40	1.87	1.4

DISCUSSION

The discussion can be enhanced by providing a deeper explanation of the wear mechanisms observed during the experiments. the manuscript should relate the wear tracks, debris morphology and surface changes to known mechanisms such as adhesive wear, abrasive wear, oxidative wear or fatigue wear. linking these mechanisms to material properties, applied load, sliding speed and environmental conditions will give a clearer understanding of how the materials behaved under tribological loading. a more detailed microstructural interpretation of wear patterns, supported by imaging or literature evidence, will allow the discussion to reflect the actual physical processes occurring at the contact interface. this will also help correlate friction behaviour with the dominant wear mechanisms observed.

CONCLUSION

The developed Pin-on-Disc Tribometer successfully measured frictional and wear characteristics of engineering materials with high accuracy and repeatability. The experimentation demonstrated that aluminum alloy possesses superior wear resistance, while mild steel exhibits higher friction due to adhesive contact. The results closely followed the ASTM G99 trends, confirming the system's validity.

The tribometer proved to be an efficient, low-cost, and educationally valuable setup for tribological studies. It provides mechanical engineering students and researchers with a hands-on platform to investigate material behavior under controlled loading and speed conditions. The integration of sensors and digital acquisition improved precision and data reliability.

Future developments include incorporating temperature sensors, lubricant flow systems, and AI-based data analytics for real-time wear prediction. The study confirms that laboratory-scale tribometers can effectively replicate industrial testing scenarios and contribute significantly to material development and design optimization.

the performance evaluation of the pin on disc tribometer for friction and wear measurement in engineering materials demonstrates its reliability as a fundamental tool for characterising tribological behaviour under controlled laboratory conditions. the study confirms that the tribometer allows accurate assessment of friction coefficient trends and wear rate variations across different materials, loads and sliding velocities. the experimental findings highlight the strong interplay between material microstructure, surface condition and operating parameters in governing frictional response and wear mechanisms. the observed wear patterns and debris morphology indicate that each material exhibits a distinct combination of adhesive, abrasive or oxidative wear depending on the imposed test conditions. the results underline the importance of proper calibration, alignment and environmental control to minimise measurement variability and ensure reproducible outcomes. overall, the work establishes that the pin on disc method remains an effective approach for comparative evaluation of engineering materials, providing essential data for material selection, surface engineering and component design in tribology related applications. the insights obtained from the experiments add value to existing literature by offering a clearer understanding of how friction and wear behaviours evolve with operational factors and material characteristics. this contributes to improving predictive models, enhancing component durability and reducing energy losses in mechanical systems where sliding contact occurs.

FUTURE SCOPE

Future work can extend this study by integrating more advanced diagnostic tools and modelling approaches to strengthen the understanding of tribological interactions. incorporating optical profilometry, surface texture analysis and high-resolution imaging methods such as scanning electron microscopy can offer deeper insights into wear scar evolution and microstructural alterations at the contact interface. applying machine learning tools or numerical simulations can help predict friction and wear responses under varying loads and speeds with higher accuracy. future investigations may also include tests under lubricated conditions, elevated temperatures and corrosive environments to replicate real world applications more closely. exploring environmentally friendly materials, composite coatings and surface modification techniques can widen the applicability of the results to emerging engineering challenges. expanding the uncertainty and error analysis by adopting more rigorous statistical techniques will further improve the reliability of the measurements. such advancements will not only refine the performance evaluation of pin on disc tribometers but also contribute to the development of more durable, energy efficient and sustainable engineering materials and tribological systems.

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