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Design and Fabrication of a Coefficient of Friction Measuring Device with Local Material for use in University Laboratories

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ABSTRACT

The significance of understanding friction and the coefficient of friction (COF) is paramount in engineering education, technology, and in developing countries like Nigeria. The high cost of importing essential equipment has limited many learners' access to vital practical experiences. As a solution, locally sourced and affordable materials have been utilised to create a friction measuring tool for university laboratories, enabling hands-on learning and practical application of key concepts. This fabricated tool experimented with wood, ceramic, plastic, and glass surfaces. The experiment tested four different combinations of surfaces: wood on wood, wood on ceramic, wood on glass, and wood on plastic. The results showed that wood has the highest COF with wood (0.52) followed by plastic (0.47), glass (0.4) and ceramics (0.38). However, wood has the lowest COF with ceramics meaning wood on ceramic surfaces are more prone to sliding than other surfaces tested. The results were compared and agreed with the existing literature on the subject.

Keywords: Coefficient of friction; University Laboratory; Measuring Device; Design and Fabrication; Local Materials

1.0 INTRODUCTION

Understanding the coefficient of friction is paramount in mechanical systems due to its influence on force, wear, and efficiency. This dimensionless ratio of force to normal force is affected by factors such as surface roughness [1], [2], material type, temperature, and lubrication. The coefficient of friction is extensively utilised in designing car brakes and tyres, as well as in geological fault analysis and material development. Its comprehension and control are crucial for performance, reliability, safety, energy consumption, and environmental impact [3]. In the design and performance of machinery, gears, and bearings, friction coefficients play a critical role. A comprehensive grasp of these coefficients is essential to ensure optimal performance and minimal energy wastage [4]. In the automotive sector, data on friction coefficients are vital for enhancing tire-road interactions, optimizing braking systems, and ensuring safety [5], [6]. Material and coating selection for various applications is influenced by friction coefficients, directly impacting product performance and durability [7]. Minimizing friction in aircraft components can improve efficiency, leading to better fuel economy and increased safety measures. Therefore, precise determination of friction coefficients holds utmost importance in aircraft design [8], [9]. In the medical field, friction coefficients are significant in the design of artificial joints and medical

instruments, ensuring patient safety and comfort [9], [10]. Furthermore, controlling the coefficient of friction is crucial in sports equipment design, such as footwear, to enhance performance and prevent injuries [11]. Friction coefficients are vital for studying tectonic plate movements and predicting seismic events in geological research [12], [13]. Additionally, the concept of friction coefficients is fundamental in physics and engineering courses, contributing to the education of future scientists and engineers [14], [15]. The field of tribology relies heavily on precise measurements of friction coefficients to develop lubrication technologies and reduce wear in various applications [16]. Table I presents the coefficient of friction for different surfaces [17].

This device has been created with a focus on cost-effectiveness, making it accessible to educational institutions with limited budgets. It is equipped with readily available and affordable components, and is user-friendly, making it suitable for students, researchers, and educators. The device has an intuitive interface, clear instructions, and minimal setup requirements. Despite its low cost, it maintains a high level of accuracy in measuring the coefficient of friction and is calibrated to provide reliable data for academic and research purposes. The device is compact and lightweight, allowing for easy transport between laboratories and classrooms, and its portability enhances its versatility. It can accommodate a variety of test samples and surface materials, enabling a wide range of experiments and research projects related to friction.

The measurement of the coefficient of friction has undergone significant changes over time, transitioning from basic and rudimentary techniques to more sophisticated and precise methods. Initially, measurements relied on simple approaches that involved inclines and weights, where the frictional force was balanced against gravitational forces [18], [19]. In the 19th century, the development of instruments such as the inclined plane apparatus introduced a more systematic approach to measuring friction [20]. Subsequently, sliding block devices gained popularity as a means of measuring friction, enabling more controlled and repeatable experiments [21]. As the 20th century progressed, advanced tribometers and friction testing machines emerged, capable of accurately measuring the coefficient of friction under various conditions and materials [22]. Furthermore, with the advancements in nanotechnology, micro and nanoscale tribometers were developed to study friction at extremely small scales [23]. In recent years, computer simulations have become an integral part of friction assessment, complementing experimental techniques by allowing for virtual evaluations of frictional behaviour [24]. The evolution of coefficient of friction measurement methods signifies the progress in scientific knowledge and technological capabilities, leading to a better understanding of friction in diverse applications and fields. The device has been designed to measure the coefficient of friction cost-effectively, making it accessible to educational institutions with limited budgets. Equipped with affordable components and a user-friendly interface,

The Pin-on-Disk Tribometer utilizes a rotating disk with a pin or ball sliding against it to measure frictional force. However, it has limitations as it is only suitable for flat surfaces and may not accurately simulate real-world conditions. Additionally, it can be costly [25].

The Block-on-Ring Tribometer involves a block or sample pressed against a rotating ring to measure frictional forces. However, this apparatus is limited to specific geometries and the presence of wear debris can impact the results [26].

The Four-Ball Tribometer consists of three stationary balls surrounding a fourth rotating ball, and measures the friction between them. However, this method is restricted to spherical samples and may not fully represent real-world applications [5], [27].

The Reciprocating Tribometer measures friction between two surfaces using back-and-forth motion. While it is specifically designed for reciprocating motion applications, wear can affect its accuracy [1], [28].

Commercial Friction Testers are commercially available with automated features and data acquisition capabilities. However, they have limitations including high initial costs, limited customization, and may not be suitable for specific research requirements.

The Micro/Nano Tribometer is designed for small-scale measurements at the micro or nano level. However, it has limitations such as high cost, complexity, and the need for specialized training, making it unsuitable for larger-scale applications [29], [30].

The Ball-on-Plate Tribometer measures friction forces by pressing a ball against a flat plate. However, it is limited to specific contact geometries and may not fully represent complex surface interactions [31], [32].

Rotational Viscometers, originally designed for viscosity measurements, can be adapted for friction analysis. However, they may not provide detailed information on solid-to-solid friction, and the results can be influenced by fluid properties [33], [34].

Table 1: The standard range of coefficient of friction for the following dry friction

S/N	Name of Surfaces	Standard Range of Coefficient of Friction (μ)
1	Metal on Metal	0.15 - 0.6
2	Metal on Wood	0.2 - 0.6
3	Metal on Stone	0.3 - 0.7
4	Metal on Leather	0.3 - 0.6
5	Stone on Stone	0.4 – 0.7
6	Earth on Earth	0.2 – 1.0
7	Rubber on Concrete	0.6 – 0.9

Source: [17]

2.0 MATERIALS AND METHODS

During the process of designing and fabricating an inclined plane apparatus, several factors are considered to guarantee its functionality, precision, safety, and educational significance. An inclined plane serves as a basic mechanism that enables the examination of the impact of gravity and friction on objects as they traverse a sloped surface. The following are the primary factors that are considered throughout the design and fabrication procedure:

2.1 Governing Equation

The equation governing the physical phenomenon of incline friction is as described below

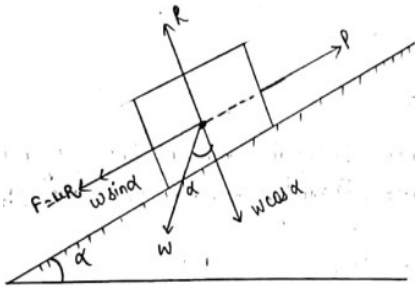


Figure 1: An inclined plane theory modelling.

Note that the left-hand side is tan θ (also μ = tan θ)

Therefore, tan θ = tan β

θ = α when the object is about to slide.

2.2 Base Plate Assembly

The task of measuring the coefficient will be easier in terms of force if the length of the inclined plane is longer. However, it is important to note that the distance will always have to change in proportion to the length because as the length increases, the angle of elevation of the ramp decreases. These parameters have an impact on the gravitational force and friction experienced by objects. In this case, the length of the inclined plane was chosen to be 660.4mm.

2.2.1 Material

The design process for a coefficient of friction measuring apparatus heavily relies on the careful consideration of material selection and size specifications. The accuracy and reliability of the measurements are directly influenced by the choice of materials, while the functionality and adaptability of the apparatus are determined by its size specifications.

When selecting the material for the inclined plane, durability and purpose were taken into consideration. Options such as wood, metal, plastic, and glass were evaluated based on their suitability for the intended use (see Table 2).

2.2.2 Surface texture

The decision on whether the surface of the inclined plane needs to be smooth, or if controlled levels of friction should be introduced, depends on the specific experiments to be conducted. In this design, a smooth surface with a measured control level was deemed appropriate.

2.2.3 Support structure

It is essential to plan and design a framework or stand that can securely hold the inclined plane in place. A sturdy base was designed to prevent any wobbling or tipping of the inclined plane, ensuring stability during experiments.

Figure 2: The coefficient of friction measuring apparatus

2.3 Angle Adjustment Mechanism

The angle adjustment mechanism in a coefficient of friction measuring apparatus is crucial for evaluating friction under different inclinations or slopes. This mechanism allows researchers or users to study how the coefficient of friction changes with varying angles, simulating real-world scenarios where surfaces may be inclined

2.3.1 Inclined Plane

a). Adjustability: The design of the inclined plane allows for adjustability, enabling variation in the angle of inclination. This feature facilitates experimentation with different slopes. Use of a simple inclined plane where the adjustable ramp is attached to the sliding component. The ramp angle can be changed to achieve different inclinations. Easy to implement, provides a continuous range of angles.

b). Measurement Tools: To accurately measure the angle of inclination, a protractor was incorporated into the design. Additionally, a ruler was included to measure distances along the incline.

2.4 Safety Considerations

When utilizing an inclined plane, safety is paramount. To guarantee safe usage, a locking mechanism has been implemented to secure the apparatus at any chosen incline angle. The physical phenomenon of incline friction governs this process. This locking mechanism is designed to withstand the forces exerted by both gravity and friction as objects are maneuvered along the plane. By engaging the lock, users can confidently adjust the incline to the desired angle without the risk of unintended slippage, thus ensuring mechanical stability. The Rails or guardrail also prevent objects from falling off the incline during experiments, rails or guardrails were incorporated into the design.

2.5 Prototyping and Testing

The creation of a prototype for the inclined plane was accompanied by a comprehensive testing phase. The primary objective of this process was to detect any potential design deficiencies, safety issues, or operational obstacles that required attention. The testing or experimentation followed a straightforward procedure, which involved adjusting the angle of inclination and applying a predetermined load. The force necessary for the sliding component to move was recorded, and these tests were repeated using various surface materials.

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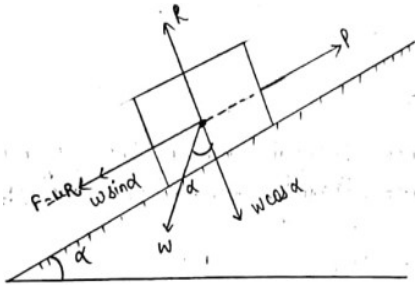


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$$\frac{f_s^{max}}{N} = \frac{Wsin\alpha\beta}{Wcos\alpha}$$

$$\frac{f_s^{max}}{N} = tan\alpha$$

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force necessary for the sliding component to move was recorded, and these tests were repeated using various surface materials.

Table 2: Geometry of the Components of Coefficient of Friction Apparatus

S/N	Components	Materials	Dimension (mm)	Weight (G)
1	Incline Plane	Wood		100
		plastic	660.4 x 152.4 x 7.6	
		ceramics	660.4 x 152.4 x 7.6	
		glass	660.4 x 152.4 x 7.6	
2	base	wood	711.2 x 177.8 x 25.4	
3	pulley	plastic	38.1ϕ	50
4	hinge	metal	127	500
5	pan	aluminum		
6	protractor	plastic		
7	ruler	Stainless steel		



Figure 3: Complete Apparatus

3.0. RESULTS AND DISCUSSION

3.1 Experiment

The experimental dataset included measurements for four different combinations of contact surfaces, including wood-wood, wood-glass, wood-plastic, and wood-ceramics. The study has the potential to be expanded to explore friction coefficients for various other combinations of contacting surfaces. Figure 4 illustrates that the normal reaction is equal to the combined weight on the surface, regardless of the material. The frictional force is calculated by multiplying the friction coefficient by the normal reaction. In essence, the frictional force represents the resisting effort. It's important to note that the frictional force is directly proportional to the normal reaction, and their ratio gives the friction coefficient. Therefore, the slope of the graph represents the coefficient of friction.

The data illustrated in the graph provides insightful comparisons of the coefficients of friction between different material pairings involving wood. Notably, the coefficient of friction is highest when wood is in contact with wood, suggesting that these two surfaces create significant resistance to sliding against each

other. Following this, wood paired with plastic exhibits a moderately high coefficient of friction, while the combination of wood and glass shows a slightly lower resistance. In stark contrast, the interaction between wood and ceramics presents the least coefficient of friction, indicating that wood glides much more easily over a ceramic surface. This means that, in practical terms, more force is necessary to slide wood across a wood surface compared to sliding it over glass or plastic. Additionally, it's important to note that the likelihood of sliding occurrences is increased when wood interacts with ceramics, as their smooth surfaces contribute to a more effortless sliding motion than the others tested.

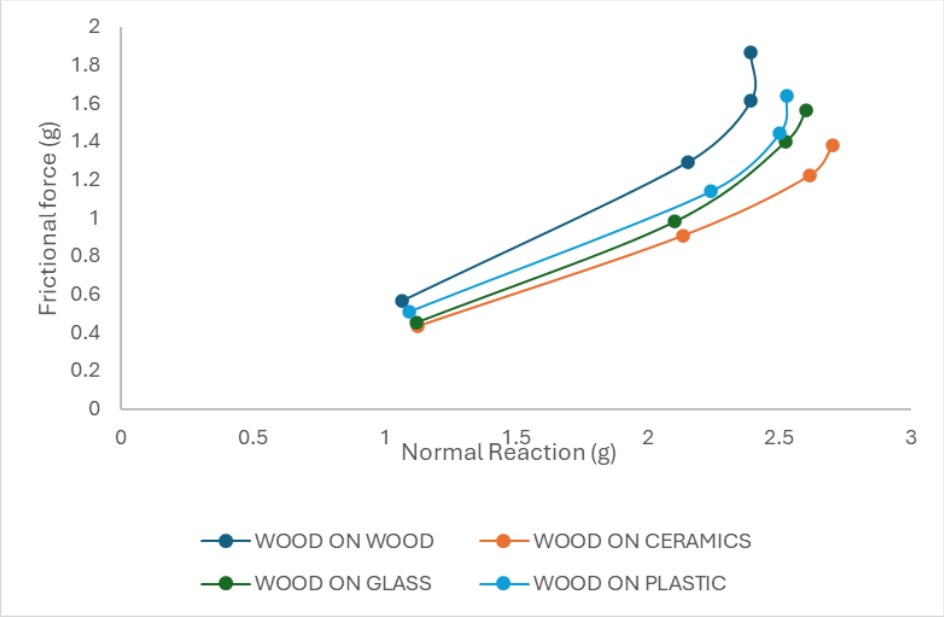


Figure 4: Coefficient of Friction of Different Surfaces using Fabricated Inclined Plane Surface Apparatus

3.2. Practical Implications:

The friction coefficient between wooden surfaces is essential for maintaining a secure grip and enhancing performance, particularly in sports like baseball and gymnastics that utilize wooden equipment. Recognizing this critical factor is invaluable across multiple industries, influencing design choices, guaranteeing safety, and elevating the functionality and effectiveness of a wide range of products and structures. When sliding functionality takes center stage in design, ceramics are unequivocally the superior material choice amidst the tested surfaces.

Mastering the principles of friction is essential for engineers and manufacturers to confidently select the best materials for their designs. This expertise directly leads to the creation of effective, high-performing solutions tailored to any application.

4.0. CONCLUSION

The study demonstrates the successful design and fabrication of a cost-effective coefficient of friction measuring device using locally sourced materials. This device bridges the gap in laboratory tools, making

practical education more accessible in universities with budget constraints. The apparatus provides reliable and accurate measurements of the coefficient of friction across different surface combinations. It underscores the importance of understanding frictional properties in material selection and system design for engineering applications.

Device Performance: The fabricated device offers an accepted level of accuracy and It is lightweight, portable, and user-friendly, making it ideal for educational purposes.

Material Analysis: The highest coefficient of friction was observed for wood-on-wood surfaces (0.52), followed by wood-on-plastic (0.47), wood-on-glass (0.40), and wood-on-ceramic (0.38). Wood-on-ceramic interactions exhibited the lowest friction, suggesting better-sliding performance for this combination.

Practical Implications: The findings are valuable for industries such as sports equipment design, where grip and sliding characteristics are critical. Ceramic surfaces are advantageous in applications prioritising ease of sliding.

Educational Impact: The device enables hands-on learning for students and researchers, fostering a deeper understanding of tribological principles.

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