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The Frictional Properties of Shoe Soles on Leather Flooring

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Abstract

This paper investigates how variations in leather flooring materials affect shoe sole friction, with the aim of enhancing anti-slip safety. Injuries due to slipping and falls are common safety hazards in daily life, and smooth and wet surfaces as well as the use of certain flooring materials may increase the occurrence of such injuries. The experimental procedures choose floor leather as the ground material, which is waterproof, environmentally friendly, economical, and has a wide range of applications. By measuring the maximum static friction force and calculating the maximum static friction coefficient of different shoe soles on leather flooring under different roughness and moisture conditions, we compare and observe which materials could affect slip resistance, thereby studying how to mitigate the risk of slipping accidents. Additionally, this study hopes to enhance ground and shoe sole materials through innovative design and the development of intelligent sensing technology while balancing economic and environmental considerations. We aim to improve social safety and responsibility, prevent slipping incidents, and promote global public safety progress as a way to make the world smarter, more environmentally friendly, and safer.

Keywords: anti-slip safety, friction, friction coefficient, flooring, shoes, leather floors

1. Introduction

Slippery falls account for a significant number of accidental injuries, particularly during rainy days or rainy seasons, when wet and smooth surfaces increase the likelihood of slipping. These accidents are some of the main causes of accidents in schools, workplaces, public places, and home environments.

Statistics indicate that slippery falls contribute significantly to injury-related accidents worldwide. In the United States, accidents caused by slippery falls account for 17% of work-related accidents, 18% of public place accidents, and 20% of domestic accidents. There are approximately 250000 to 300000 disability accidents caused by falls and injuries each year, with a death toll of 1200 to 1600 people. In the UK, slip and fall accidents account for 20% of work-related accidents, with approximately 40000 incidents per year. In Finland, work-related accidents caused by falls and injuries account for 34%, 28%, and 21% of total work-related accidents each year in the manufacturing, construction, and transportation industries, respectively. In China, there are as many as 9 million people who fall every year due to slippery surfaces. According to the Health and Safety Commission, there were approximately 10000 major workplace accidents involving ground slips and trips in 2015 alone (Sohu.com, 2019).

Slippery falls and injuries often occur in public places, residential areas, and outdoor activities. In particular, people are especially prone to slipping in public places such as shopping malls, supermarkets, and hospitals due to dense crowds, slippery floors, slopes, or numerous obstacles. Toilets, kitchens, and other slippery areas in residential buildings are also common locations for falls and injuries (Li et al., 2020; Chen et al., 2020; Wang et al., 2022). The expansion of the global construction industry, especially in the construction of public places, has resulted in increasingly sophisticated and aesthetically pleasing floor designs. However, anti-slip measures are often overlooked, thereby leading to the prevalence of falls and injuries (Zhao et al., 2017).

The slip resistance of shoe soles directly affects the comfort and safety of the shoe. Poor traction increases the risk of slipping and falling while walking, especially on wet and smooth surfaces (Wang et al., 2022). This research aims to study the friction of various shoe sole materials on leather flooring under different roughness and moisture conditions, and observe any trends in sole friction performance. Through a series of controlled experiments, we hope to promote anti-slip safety by exploring different materials and design factors. By doing so, we aim to further develop scientific, economic, and sustainable safety guarantees.

2. Background

2.1 Foundational Concepts

The foundational concepts referred to in this paper are as follows:

Friction: When two objects in contact with each other undergo relative motion or have a tendency towards relative motion, a force is generated on the contact surface that impedes the relative motion or tendency towards relative motion.

Static friction force: When two objects are relatively stationary but have a tendency to move relative to each other, the frictional force between them is called the static friction force. The magnitude of static friction force is proportional to the magnitude of the external force, but the static friction force reaches a maximum value called the maximum static friction force.

Static friction coefficient: The static friction coefficient, μ_s, refers to the ratio of the tangential force required to initiate relative motion between two objects in a relatively stationary state to the normal load. The mathematical expression for this relationship is:

$$Fs = \mu_s \times N \qquad (1)$$

2.2 Factors Affecting the Static Friction Coefficient

The magnitude of the static friction coefficient is influenced by various factors, including the following:

- Contact surface properties: Contact surfaces of different materials have different frictional properties, and so the static friction coefficient will also vary with the material (Li, 2020).
- Surface roughness: Generally speaking, rougher surfaces will exhibit a higher static friction coefficient. This is because the rough surface increases the mechanical interlocking between the contact points, thereby increasing the frictional

force (Yang, 2021).

- Temperature: Changes in temperature may affect the surface properties of materials, thereby altering the static friction coefficient. For example, certain materials may become smoother at high temperatures, thereby leading to a decrease in the static friction coefficient.
- Contact surface humidity: Humidity also has an impact on the static friction coefficient, especially for some highly hygroscopic materials. Changes in humidity can significantly alter the properties of a surface, thereby affecting the static friction coefficient.

2.3 Measurement of the Static Friction Coefficient

The static friction coefficient can be measured using the tension method (Liu et al., 2020). The tension method involves measuring the force at which an object begins to slide by applying horizontal tension or thrust—the static friction coefficient can be calculated as the ratio of force to downward force. The static friction coefficient is a core parameter for studying slip resistance, which directly reflects the ability of an object to resist sliding in a stationary state. By measuring and analyzing the static friction coefficient, the slip resistance of shoes under different material, design, technology, or environmental conditions can be evaluated (Wu et al., 2018).

3. Experimental Design and Data Collection

3.1 The Testing Surface

This experiment used leather flooring as the test surface as shown in Figure 1. Leather flooring is a rubber plastic product and one of the widely used flooring materials in the present day (Jia & Xie, 2020). Leather floors have good environmental protection, waterproof, and anti-slip properties, featuring smooth surfaces that are easy to clean and maintain. After special treatment, leather floors can exhibit high surface hardness, strong corrosion resistance, and good wear resistance. Leather flooring has been widely used in various damp areas such as bathrooms, kitchens, balconies, as well as more generally in schools, residences, offices, shops, exhibition halls, and other places.

Figure 1: A leather floor as a test surface.

3.2 Leather Flooring Roughness

Electron microscopy observations reveal that the surface of a leather floor is smooth. Hence, to obtain leather floor surfaces with varying roughness, different grades of sandpaper were used to polish the material along a consistent direction. This study examines the impact of different roughness surfaces and the orientation of abrasion marks on the friction force (Wang & Wang, 2022). Additionally, the moisture conditions of the leather flooring surfaces were modified by applying water (Zhao et al., 2017).

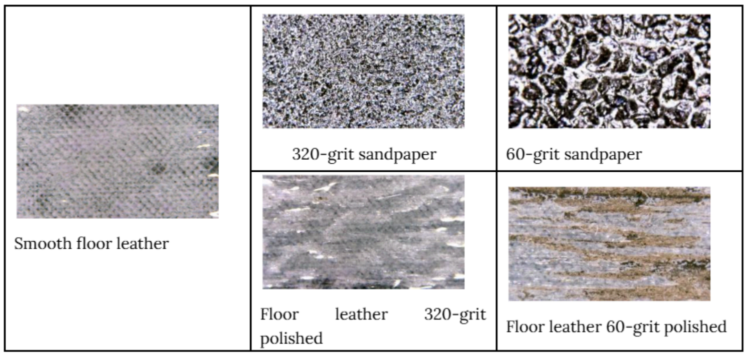


Figure 2: Various grades of sandpaper and leather flooring with different roughness characteristics, photographed using a Le Yue Professional Electron Microscope with model Z05-3. The magnification of the microscope is 200X.

The experiment uses 320-grit sandpaper and 60-grit sandpaper. The grit size of sandpaper refers to the number of abrasive particles per square centimeter. Hence, a higher grit size indicates finer sandpaper, while a lower grit size corresponds to a coarser sandpaper. As shown in Figure 2, under the microscope, we observe that the surfaces of leather floors exhibit different roughness characteristics after being polished with sandpaper of different grades.

3.3 Selection of Test Materials

Five types of shoes—including plastic slippers, cloth-soled cotton shoes, bulltendon-soled cloth shoes, sneakers, and leather shoes—were tested for their frictional characteristics in conjunction with the aforementioned experimental procedures involving the leather flooring. Each type of shoe exhibits different sole materials and patterns; the characteristics of each shoe are recorded separately in Figure 3.

Plastic slippers	Cloth-soled cotton shoes	Bulltendon-soled cloth shoes	Sneakers	Leather shoes
				
				
				
0.109 kg	0.145 kg	0.166 kg	0.374 kg	0.381 kg

Figure 3: Close-up images of different shoes, their soles, and their weights.

3.4 Experimental Procedure

3.4.1 Measurement method

As shown in Figure 4, the weights of the different shoes are measured and two identical dumbbells are added to provide downward force. The weight of each dumbbell is 1kg, and the total weight of the two is 2kg. Using the WD digital handheld push-pull force gauge with model KF-50, the maximum static friction force during the shoe pushing process can be recorded (Li, 2020). KF-50 records the maximum value during force application via the "Peak" mode. Due to the fact that the maximum static friction force is slightly greater than the sliding friction force, the maximum value of this friction force can be considered as the maximum static friction force. Thus, the maximum static friction coefficient can ultimately be used as an indicator of the slip resistance for each shoe on the leather flooring.

Friction measurement method

Dynamometer mode and display panel

Figure 4: A visualization of the experimental setup for the friction test and tools used.

3.4.2 Computing the maximum static friction coefficient

The experiment records data from 10 repeated trials under each condition. For each condition, the average maximum static friction force value is computed and the maximum static friction coefficient is obtained by calculating the downward force due to gravity, as shown in Table 1.

Table 1: The experimental data record for dry and smooth floor conditions.

Shoe type	Force of Dumbbell (N)	Force of shoe (N)	Maximum static friction force (N)										Average friction force (N)	Coefficient of friction
			1	2	3	4	5	6	7	8	9	10		
Cloth-soled cotton shoes	19.85	1.42	6.08	5.43	6.20	6.24	6.55	6.36	6.20	5.33	6.15	6.32	6.09	0.29
Plastic slippers	19.85	1.07	10.70	10.96	11.42	11.14	11.10	11.00	10.85	11.21	11.67	11.38	11.14	0.53
Bulltendon-soled cloth shoes	19.85	1.63	17.23	17.42	17.01	16.64	16.48	17.43	17.02	17.40	16.74	16.36	16.97	0.79
Sneakers	19.85	3.67	16.31	16.34	15.66	16.08	15.71	15.17	16.56	16.56	15.75	16.43	16.06	0.68
Leather shoes	19.85	3.73	19.56	19.17	19.17	20.81	20.57	20.92	19.93	18.80	19.17	20.72	19.88	0.84

We use the following formulas:

Downward force: the force exerted by the weight of dumbbells and shoes;

$$F_s = F_{dumbbell} + F_{shoe} \qquad (2)$$

Maximum static friction force: the average value of the maximum static friction force measured multiple times under specific experimental conditions, thereby giving us the maximum static friction coefficient:

$$\mu_s = \frac{F_s}{N} \qquad (3)$$

The experiment measures the changes in maximum static friction force under different test surface conditions and different shoe sole conditions. The maximum static friction coefficient is calculated under each condition, whence the slip resistance under varying conditions is analyzed by comparing the maximum static friction coefficient in each scenario.

4. Results

4.1 Data

By sanding the leather floors with different grit sandpapers to change the roughness, we apply friction parallel or perpendicular to the direction of the abrasion and change the testing conditions of the leather flooring by sprinkling water to vary the dryness and wetness. A matrix table was then established and data were collected for each condition, whence the maximum static friction coefficients were calculated. The final data obtained are shown in Table 2.

Table 2: Maximum static friction coefficients under different conditions. Parallel/Perpendicular: Direction between abrasion marks and friction force.

Surface conditions for leather floor			Shoe type				
Dry or wet	**Surface roughness to be tested**	**Direction of friction force**	**Cloth-soled cotton shoes**	**Plastic slippers**	**Bulltendon-soled cloth shoes**	**Sneakers**	**Leather shoes**
Dry	Smooth interface		0.29	0.53	0.79	0.68	0.84
Dry	320-grit polished	Parallel	0.24	0.48	0.77	0.60	0.73
Dry	320-grit polished	Perpendicular	0.31	0.55	0.84	0.80	0.86
Dry	60-grit polished	Parallel	0.34	0.57	0.74	0.66	0.74
Dry	60-grit polished	Perpendicular	0.49	0.63	0.87	0.84	0.80
Wet	Smooth interface		Condition omitted because the sole is not waterproof.	0.73	0.57	0.57	1.01
Wet	320-grit polished	Parallel		0.65	0.59	0.76	0.81
Wet	320-grit polished	Perpendicular		0.74	0.77	0.83	0.82
Wet	60-grit polished	Parallel		0.66	0.64	0.79	0.75
Wet	60-grit polished	Perpendicular		0.80	0.78	0.92	0.78

4.2 Maximum Static Friction Coefficient of Different Sole Materials

The maximum static friction coefficients of different shoes on dry and smooth leather floors were collected, as shown in Figure 5.

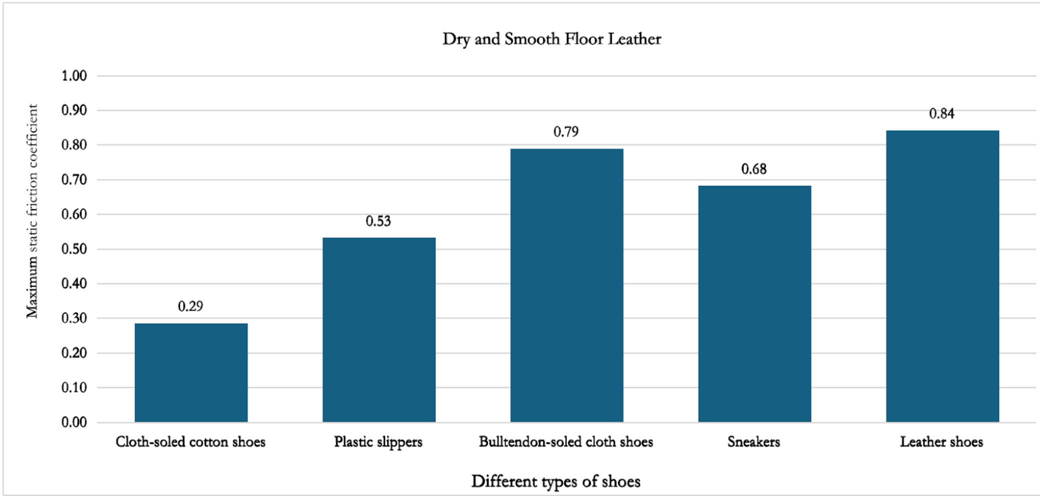


Figure 5: Maximum static friction coefficients of different shoes on dry and smooth leather floors.

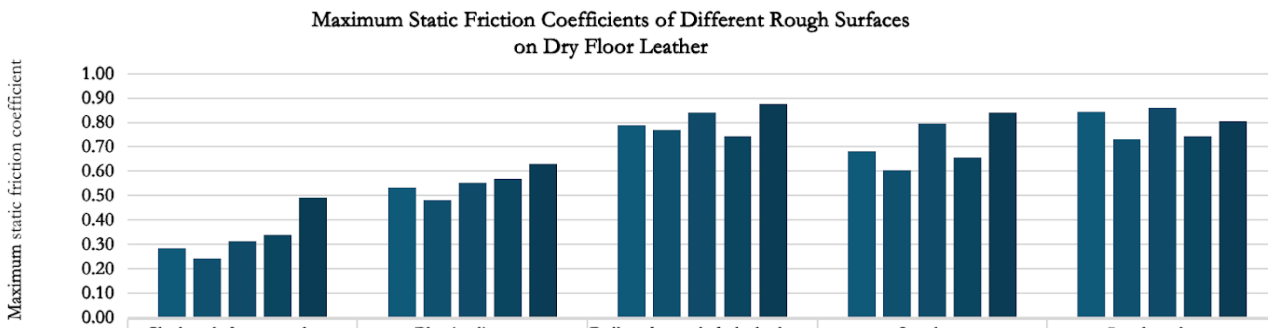
The maximum static friction coefficient of cloth-soled cotton shoes was found to be the smallest, at 0.29, or less than 0.3. Other types of shoe soles have a maximum static friction coefficient of 0.5 or above, indicating excellent slip resistance. In particular, leather shoes exhibited a maximum static friction coefficient, exceeding 0.8 and reaching 0.84. Shoes with a higher maximum static friction coefficient have better slip resistance and are suitable for use on wet, sloping, or smooth surfaces, providing higher safety and stability. The maximum static friction coefficient of different shoes varies, directly affecting their anti-slip properties, stability, and applicability. Appropriate shoes should be selected based on specific use cases, activity types, and safety needs.

4.3 The Influence of Surface Roughness of the Test Surface on Friction Force

After polishing the leather floors with sandpaper of different grades, test surfaces of leather flooring with different roughness were obtained. As shown in Figure 6, the surfaces of the unpolished leather floors were smooth, while the surfaces of the leather floors polished with 320-grit sandpaper had slight and shallow scratches. The surface of the leather floors polished with 60-grit sandpaper had deeper and coarser scratches.

Figure 6: Microscopic characteristics of leather floors with different roughness.

Sandpaper is polished in the same fixed direction, and then friction force is applied parallel or perpendicular to the polishing direction, thereby obtaining different friction coefficients in the direction parallel or perpendicular to the grinding. The relationship between friction force and grinding direction has a direct impact on the static friction coefficient (Wang & Wang, 2022). Hence, the grinding direction plays an important role in the practical application of anti-slip floor materials.



	Cloth-soled cotton shoes	Plastic slippers	Bulltendon-soled cloth shoes	Sneakers	Leather shoes
Smooth interface	0.29	0.53	0.79	0.68	0.84
320-grit polished parallel	0.24	0.48	0.77	0.60	0.73
320-grit polished perpendicular	0.31	0.55	0.84	0.80	0.86
60-grit polished parallel	0.34	0.57	0.74	0.66	0.74
60-grit polished perpendicular	0.49	0.63	0.87	0.84	0.80

Figure 7: Maximum static friction coefficient of different rough surfaces on dry leather floors. Parallel/Perpendicular: Direction between abrasion marks and friction force.

As shown in Figure 7, through experimental data analysis, it can be concluded that:

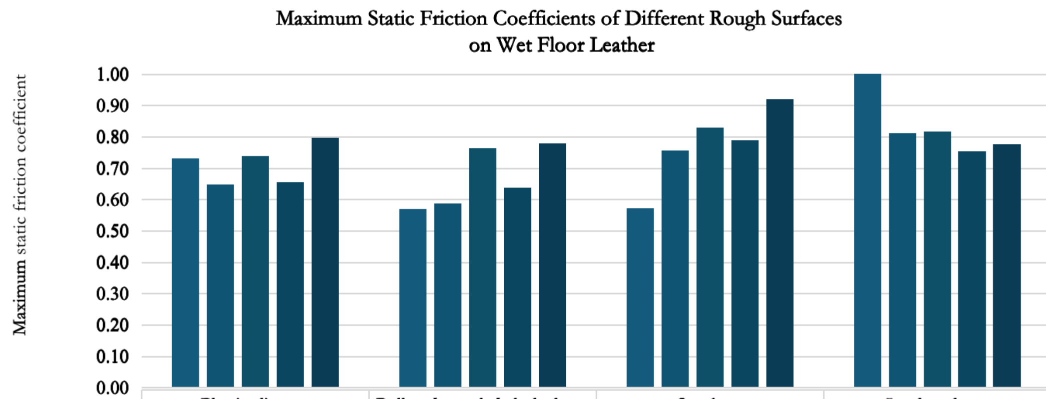
1) Changes in surface roughness of the test surface will directly affect the friction coefficient between two identical materials.

2) Varying the roughness affects the maximum static friction coefficient, and for most materials used in this study, the friction coefficient of rough surfaces is greater
in the direction perpendicular to the rough marks.

3) At the same roughness, the friction coefficient in the direction perpendicular to the abrasion marks is greater than that in the parallel direction.

4) Abrasion marks may not necessarily increase the maximum static friction coefficient, and applying force in the parallel direction to the abrasion marks may decrease the maximum static friction coefficient.

As shown in Figure 8, on wet test surfaces, most materials exhibit similar anti-slip phenomena and conclusions as on the dry test surface. The reader may refer to the relevant experimental data analysis on Figure 7 in Section 4.3.



	Plastic slippers	Bulltendon-soled cloth shoes	Sneakers	Leather shoes
smooth interface	0.73	0.57	0.57	1.01
320-grit polished parallel	0.65	0.59	0.76	0.81
320-grit polished perpendicular	0.74	0.77	0.83	0.82
60-grit polished parallel	0.66	0.64	0.79	0.75
60-grit polished perpendicular	0.80	0.78	0.92	0.78

Figure 8: Maximum static friction coefficient of different rough surfaces on wet leather floors. Parallel/Perpendicular: Direction between abrasion marks and friction force.

4.4 Effects of Different Dry and Wet Conditions

In the experiment, the moisture conditions of the leather flooring test surface were changed by sprinkling the test surface with water to gauge the variation in the maximum static friction coefficient on wet ground. On a smooth test surface, wetness conditions appear to affect the variation of the maximum static friction coefficient (Zhao et al., 2017). As shown in Figure 9, under wet conditions, the friction coefficient of two experimental samples of bulltendon-soled cloth shoes and sneakers decreased, while the friction coefficient of the other two samples of plastic slippers and leather shoes increased.

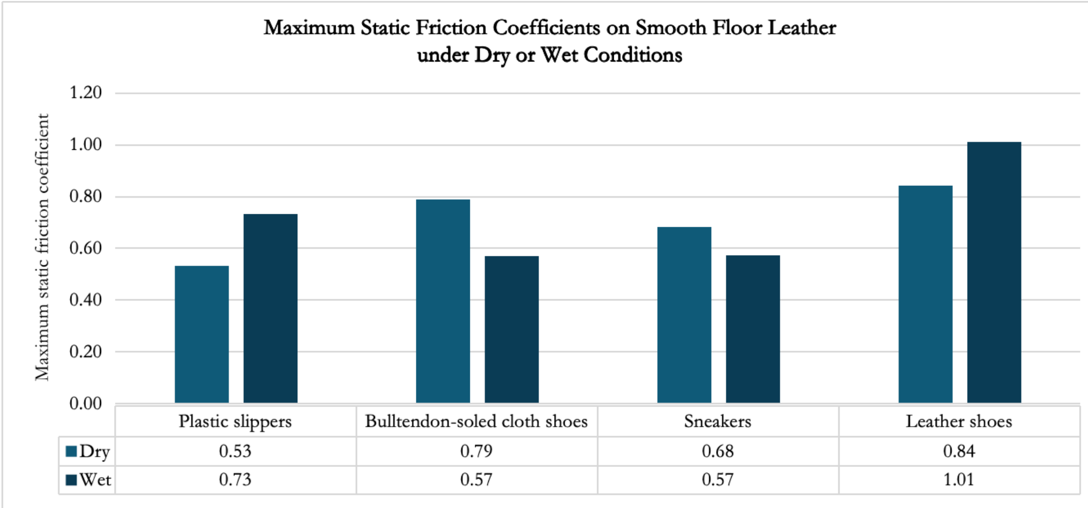


Figure 9: Maximum static friction coefficients on smooth leather floors under dry or wet conditions.

For rough surfaces, humid environments can also influence changes in the friction coefficient, although the magnitude of the change in friction coefficient is not as large as that of smooth surfaces. In the direction parallel to the abrasion marks, the friction coefficient of 3 out of 4 samples increased on the wet test surface in comparison to the dry test surface, as shown in Figure 10 (Yang, 2021).

Prior research has shown that in some cases, wet ground can lead to increased friction (Liu et al., 2020). This may be the result of multiple factors such as the formation of liquid film and surface adhesion, the increase in the area of contact between liquid film and objects and ground, and the interaction between water molecules and object surfaces (Wu et al., 2018; Jia & Xie, 2020).

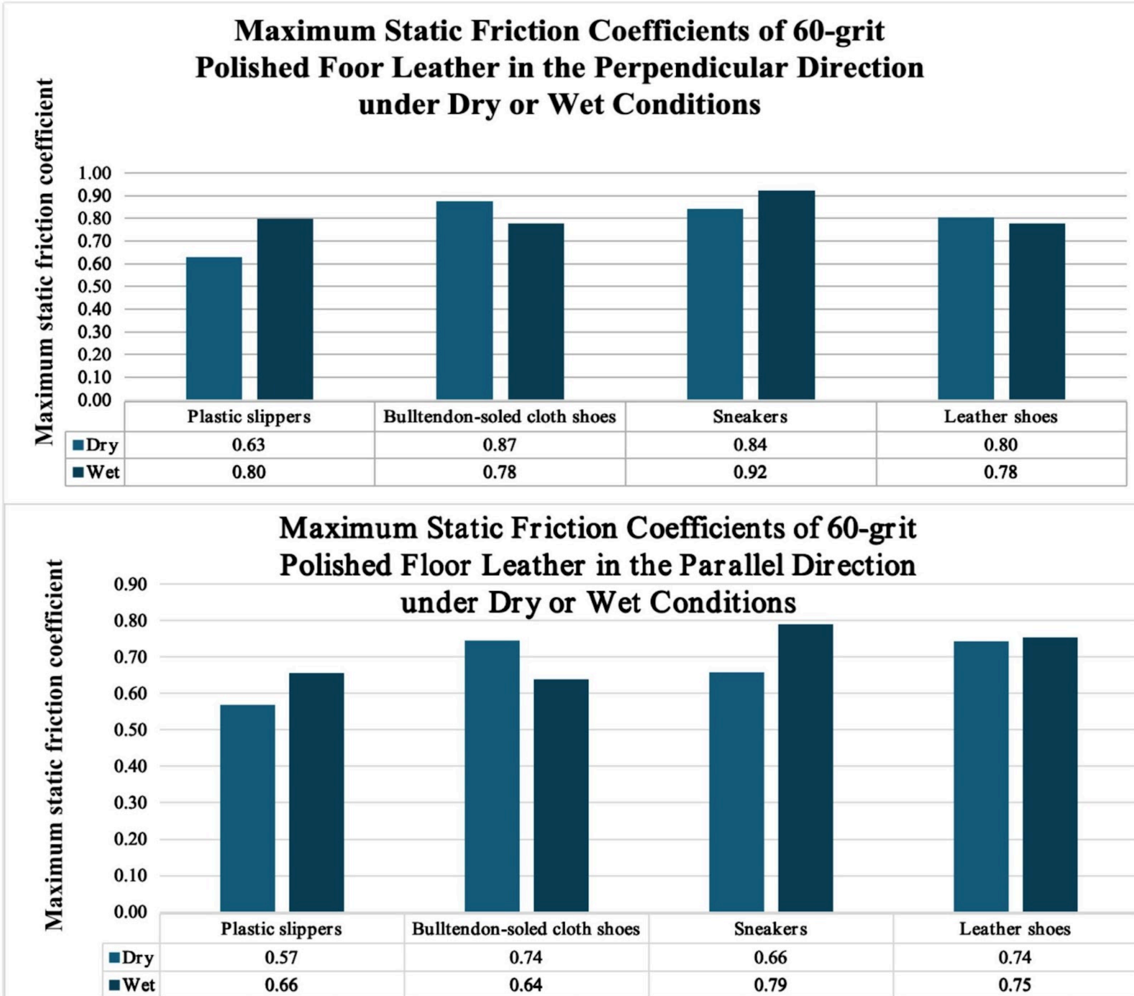


Figure 10A: Maximum static friction coefficient under different rough surfaces and moisture conditions. Parallel/Perpendicular: Direction between abrasion marks and friction force.

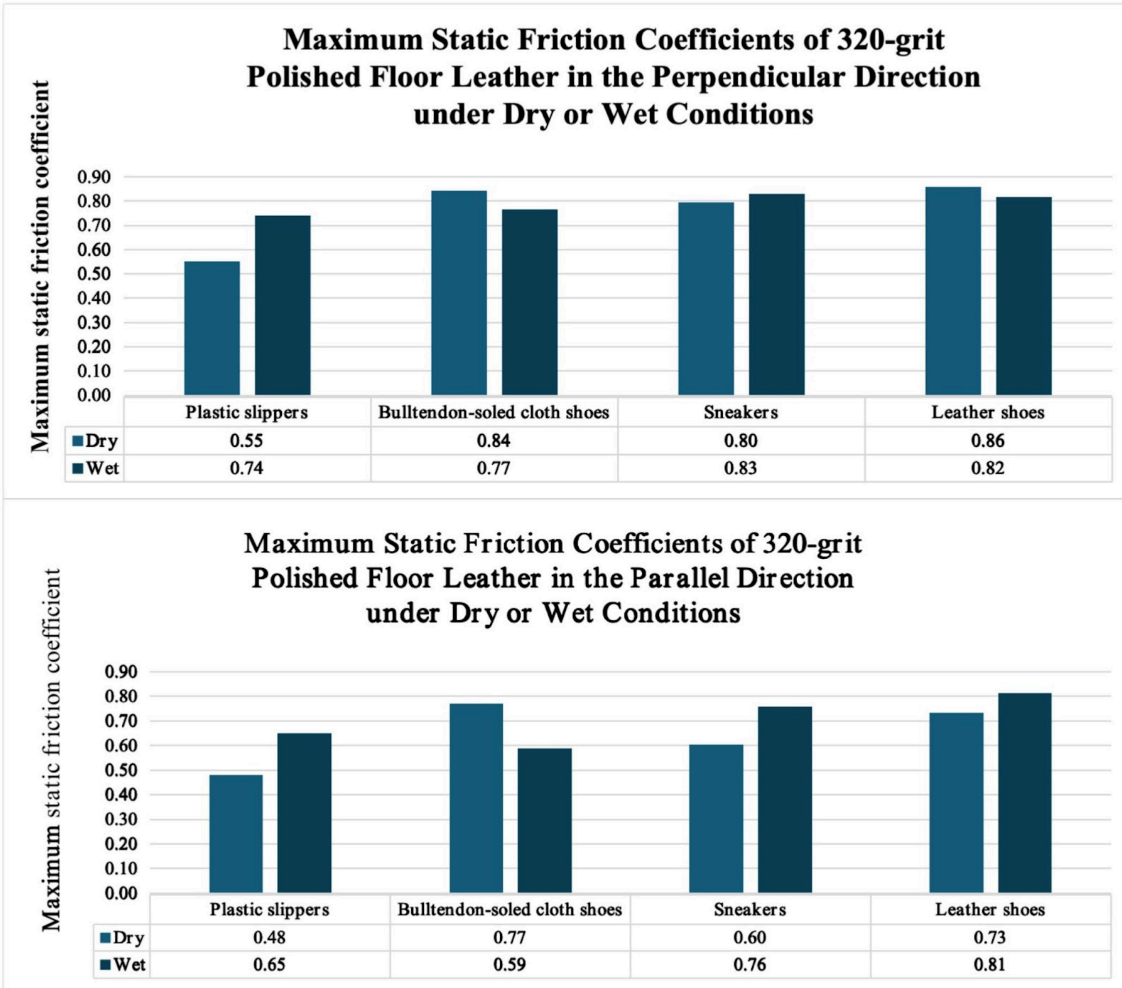


Figure 10B: Maximum static friction coefficient under different rough surfaces and moisture conditions. Parallel/Perpendicular: Direction between abrasion marks and friction force.

5. Conclusion and Future Directions

This study conducted a series of experiments to study changes in the maximum static friction coefficient of shoe soles under different roughness and moisture conditions. Based on experimental results and data analysis, the following conclusions were drawn:

1) The maximum static friction coefficient varies depending on the sole and floor materials.
2) Surface roughness affects the friction of the sole.

3) The direction of surface abrasion can affect the maximum static friction coefficient.
4) Under wet conditions, some materials exhibit a significant reduction in the maximum static friction coefficient.

Considering the aforementioned conclusions, floor and sole materials with good slip resistance should be chosen. Furthermore, the roughness of the ground material should be increased, with the direction of abrasions controlled to be perpendicular to the walking direction.

Future research could explore how the frictional force changes under further varying moisture conditions to better understand how moisture affects slip resistance. Additionally, investigating how the friction force varies more precisely with the direction of abrasions and walking direction at different angles—such as in multiple or irregular directions—could provide deeper insights into real-world walking conditions. Furthermore, the results of this study could be expanded to other environmental conditions by exploring the slip resistance of more ground materials.

Further advancements in material research and improvement can lead to the development of new anti-slip materials with improved friction coefficients, enhancing both ground and sole materials for better design, quality, and overall safety. With this, balancing economic growth with environmental sustainability is essential, since evaluating anti-slip performance in different risk areas can help guide material selection while promoting market development of improved, safer flooring and shoe sole materials.

Strengthening social security and responsibility is also crucial in minimizing the occurrence of slip-related accidents, medical expenses, compensation costs, and the physical and mental toll of injuries. Establishing unified safety standards in this context can further enhance public safety on a global scale. Additionally, developing intelligent sensing technology that automatically adjusts slip resistance properties based on human weight and environmental conditions through downward force and moisture sensors could significantly improve safety measures. By exploring innovation in these fields, we hope to create a smarter, more environmentally friendly, and safer world.

6. References

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About the author

Shao Jiazhuo is a first-year student at the No.2 High School of East China Normal University, Lin-gang Fengxian Branch. He previously attended Shanghai Zhangjiang Group Middle School, where his interest in science and technology innovation was sparked by engaging coursework and the guidance of dedicated teachers. Jiazhuo has earned multiple honors in the Shanghai Youth Science and Technology Innovation Competition, including first prize, second prize, and the special prize.

At his current school, which emphasizes scientific inquiry and creativity, Jiazhuo continues to thrive in a supportive and inspiring environment. He is known for his cheerful, optimistic personality and his wide-ranging interests. An avid reader and accomplished athlete, he serves as the captain of the school's football team, having led the team to a fourth-place finish in the Shanghai municipal competition and a third-place finish in the Pudong New Area competition.

Jiazhuo is one of 100 student members selected for the 2024 World Laureates T Conference, where he participated in the Science Lesson 1 and the Tablecloth Forum, engaging with Nobel laureates and world-renowned scientists. As a young researcher at the Shanghai Youth Science Research Institute, he continues to explore cutting-edge scientific knowledge while cultivating innovative thinking. In 2025, he was selected for the prestigious Future Scientist Training Program, marking a new chapter in his pursuit of scientific discovery.