Research on the friction force of shoe soles based on floor leather materials

Abstract

Slippery falls are common safety accidents in daily life.Smooth and wet ground conditions, as well as special materials, may increase the occurrence of such injuries.This project chooses floor leather as the specific flooring material.Measure the maximum static friction force of different shoe sole materials on floor leather under different roughness, dryness, and wetness conditions,and calculate the maximum static friction coefficients to compare and observe the rules.The purpose of this project is to study how to avoid the risk of sliding accidents.Improving ground and sole materials, enhancing social safety and responsibility, balancing economy and environmental protection, through innovative design, preventing slipping incidents, creating a safer and more comfortable social environment, and promoting global public safety progress.

Keywords: Static friction force, friction coefficient, floor leather, slippery falls

1. Introduction

1.1 Research origin

During rainy days or rainy seasons, it is easy to slip while walking due to factors such as wet and smooth ground.Slippery falls account for a certain proportion of various types of accidental injuries. It's one of the main causes of accidents in schools, workplaces, public places and home environments.

1.2 Preliminary investigation

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 slippery falls and injuries each year, with a death toll of 1200 to 1600 people.In the UK, slippery falls account for 20% of work-related accidents (approximately 40000 per year).The manufacturing, construction, and transportation industries in Finland account for 34%, 28%, and 21% of the total annual work-related accidents caused by slippery falls and injuries, respectively.In China, the number of people who fall due to slippery conditions is as high as 9 million per year.According to statistics from the Health and Safety Commission, there were approximately 10000 major workplace accidents involving ground slips and trips that occurred in 2015 alone.

Slippery falls and injuries often occur in public places, home environments, and outdoor activities.Public places such as shopping malls, supermarkets, hospitals, etc. are prone to slipping due to dense crowds, slippery floors, or numerous obstacles.In the home environment, wet and slippery areas such as bathrooms and kitchens are also common places for falls and injuries.With the development of the global construction industry, especially the construction of public places, building floors are becoming increasingly high-end, gorgeous, beautiful, and magnificent.But sometimes the issue of anti-skid on the ground is overlooked, resulting in frequent accidents of slippery falls.

1.3 **Research objective**

The anti-skid performance of the sole directly affects the comfort and safety of the shoe.Poor skid resistance, easy to slip and fall while walking, especially on wet, light, and slippery roads.This project will conduct a series of experiments to study the changes in shoe sole friction based on floor leather materials under different roughness and dry or wet conditions, and observe the patterns involved.

2.Basic concepts

2.1 Basic concept explanation

Based on research, the basic concepts are as follows:

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

Static friction:When two objects are relatively stationary but have a tendency towards relative motion, the frictional force between them is called static frictional force.The magnitude of static frictional force is related to the magnitude of external force, but there is a maximum value called maximum static frictional force.

Static friction coefficient:The static friction coefficient 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. Its mathematical expression is:$F_s = \mu_s \times N$

2.2 Factors affecting static friction coefficient

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

Properties of contact surface:The contact surfaces of different materials have different friction properties, so the static friction coefficient will also vary.

Surface roughness:Generally speaking, the rougher the surface, the higher the static friction coefficient. Because the rough surface increases the mechanical interlocking between the contact points, thereby increasing the frictional force.

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, leading to a decrease in the static friction coefficient.

Humidity of contact surface:Humidity also has an impact on the coefficient of static friction, especially for certain materials with strong hygroscopicity.The change in humidity will significantly alter its surface properties, thereby affecting the static friction coefficient.

2.3 Detection of static friction coefficient

The detection of static friction coefficient can be calculated by measuring with tension method, that is, by applying horizontal tension or thrust, the force at which the object begins to slide is measured.The static friction coefficient can be calculated based on the ratio of force to positive pressure. The static anti-skid performance of shoes refers to the static friction coefficient between the shoe sample and the tested surface.

3.Experimental design and data recording

3.1 Test surface material

This experiment uses floor leather as the testing surface.Floor leather belongs to rubber plastic products and is one of the widely used flooring materials at present. It has good waterproof, moisture-proof, and anti slip properties.The surface is smooth and easy to clean. After special treatment, the surface hardness is high, the wear resistance is good, and it also has strong corrosion resistance.Floor leather has been widely used in various damp places such as bathrooms, kitchens, balconies, as well as commercial and public places such as schools, hotels, supermarkets, hospitals, offices, or home decoration.

Figure 1: Floor leather as test surface

3.2 Floor leather roughness

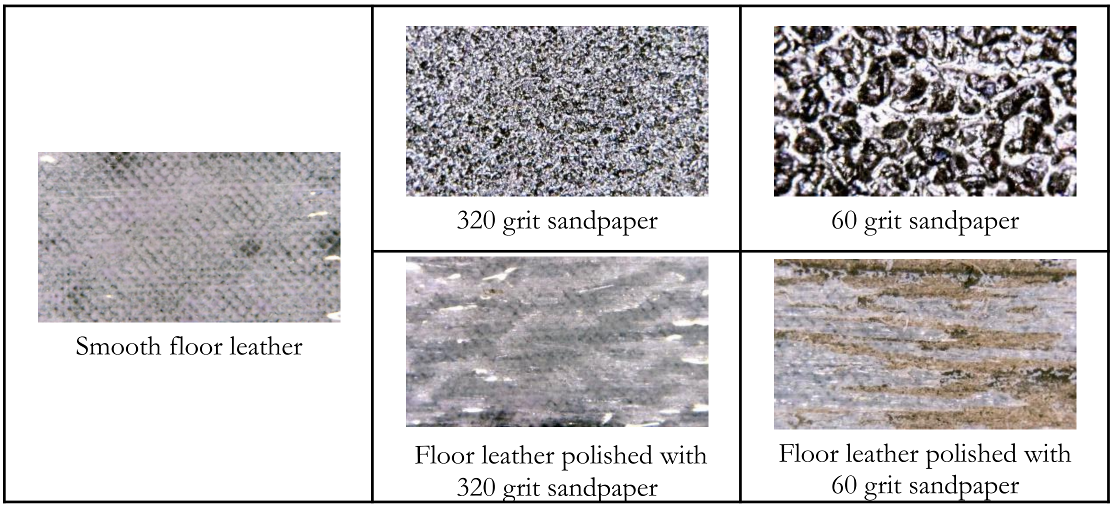


Figure 2: Under the microscope, different grades of sandpaper and floor leather with different roughness characteristics

(Using Le Yue professional electron microscope (Z05-3) for photography)

Observing through an electron microscope,the surface of the floor leather is smooth.In order to obtain floor leather surfaces with different roughness, different grades of sandpaper were used to polish along the same direction, in order to study the influence of different roughness surfaces on friction force, as well as the influence of scratch direction on friction force.At the same time, the dry or wet conditions of the floor leather surface can be changed by sprinkling water.

As shown in the above figure, under the microscope, it can be observed that the surface of the floor leather exhibits different roughness characteristics after being polished with sandpaper of different grades.

3.3 Selection of test materials

In conjunction with the testing of friction force in floor leather research, five types of shoes that are commonly worn or have distinctive features were selected, namely home slippers, cloth soled shoes, cowhide soled shoes, sports shoes, and leather shoes.These shoes have different sole materials and patterns, which are quite common. Record the quality of each shoe separately.

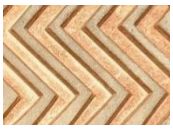
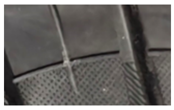
Slippers	Cloth soled cotton shoes	Bulltendon soled cloth shoes	Sneakers	Leather shoes
				
				
				
0.109 kg	0.145 kg	0.166 kg	0.374 kg	0.381 kg

Figure 3: Close ups of different shoes, soles, and shoe quality as test objects

3.4 Test plan

3.4.1 Measuring method

Measure the mass of different shoes and add two dumbbells weighing a total of approximately 2kg as a downward positive pressure.Record the maximum static friction force during the shoe pushing process using the WD digital handheld push-pull force gauge, model "KF-50".(KF-50 records the maximum value during the force application process through the "Peak" mode. As the maximum static friction force is slightly greater than the sliding friction force, this maximum friction force can be considered as the maximum static friction force).The maximum static friction coefficient can ultimately be calculated as the anti-skid performance indicator of the shoe on the floor leather.

Friction measurement method

Dynamometer mode and display panel

Figure 4: Friction test plan and tools

3.4.2 Analysis method for anti-skid performance

The experiment will collect the changes in maximum static friction force under different test surface conditions and different sole conditions, and calculate the maximum static friction coefficient under this condition. By comparing the maximum static friction coefficient, the anti-skid performance analysis under different conditions will be obtained.

3.4.3 Calculation method for maximum static friction coefficient

The experiment will record 10 repeated test data under each condition, take the average as the maximum static friction force value under that condition, and obtain the maximum static friction coefficient under that condition by calculating the positive pressure converted from gravity.

condition			Dumbbell pressure(N)	Shoe pressure(N)	Maximum static friction force(N)										friction (average value) (N)	coefficient of friction
shoe	dry or wet	Test surface to be tested			1	2	3	4	5	6	7	8	9	10		
cloth soled cotton shoes	dry	smooth interface	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	dry	smooth interface	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	dry	smooth interface	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	dry	smooth interface	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	dry	smooth interface	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

Figure 5: Experimental data record table (part)

Among them:

Positive pressure:The pressure exerted by the weight of dumbbells and shoes. $F_s = F_{哑铃} + F_{鞋子}$

Maximum static friction force: the average of multiple measurements of the maximum static friction force under specific experimental conditions.

Obtain the maximum static friction coefficient:$\mu_s = \frac{F_s}{N}$

3.5 Data table

Establish a Matrix table for each experimental condition, collect experimental data for each condition, and calculate the maximum static friction coefficient under that condition. The final data table is as follows:

Test surface conditions for floor leather			shoe				
dry or wet	Surface roughness to be tested	Direction of Friction	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 polishing	parallel	0.24	0.48	0.77	0.60	0.73
dry	320 polishing	vertical	0.31	0.55	0.84	0.80	0.86
dry	60 polishing	parallel	0.34	0.57	0.74	0.66	0.74
dry	60 polishing	vertical	0.49	0.63	0.87	0.84	0.80
wet	smooth interface		Skip this condition because the sole is not waterproof	0.73	0.57	0.57	1.01
wet	320 polishing	parallel		0.65	0.59	0.76	0.81
wet	320 polishing	vertical		0.74	0.77	0.83	0.82
wet	60 polishing	parallel		0.66	0.64	0.79	0.75
wet	60 polishing	vertical		0.80	0.78	0.92	0.78

Figure 6: Experimental data recording and summary of maximum

static friction coefficient under various conditions

4. Data analysis and conclusion

4.1 Friction coefficient of different sole materials

In the preliminary experiment, the maximum static friction coefficients of different shoes on dry and smooth floor leather were collected:

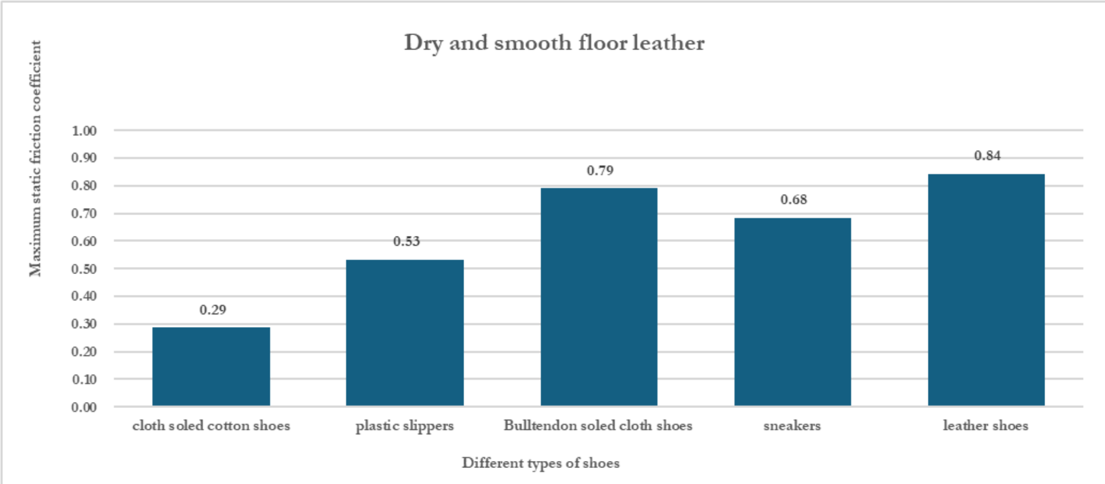


Figure 7: Maximum static friction coefficient of different shoes on dry and smooth floor leather

The maximum static friction coefficient of cloth soled shoes is the smallest, at 0.29, less than 0.3.The friction coefficient of various shoe soles is above 0.5, especially for leather shoes, which exceeds 0.8 and reaches 0.84, with a significant difference.

4.2 The influence of surface roughness of the test surface on friction

4.2.1 Polishing with different grades of sandpaper

After polishing the floor leather with sandpaper of different grades, test surfaces of floor leather with different roughness were obtained.From the figure below, it can be seen that the surface of the unpolished floor leather is smooth, while the surface of the floor leather polished with 320 grit sandpaper has slight and shallow scratches. The surface of the floor leather polished with 60 grit sandpaper has deeper and coarser scratches.

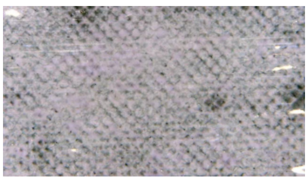
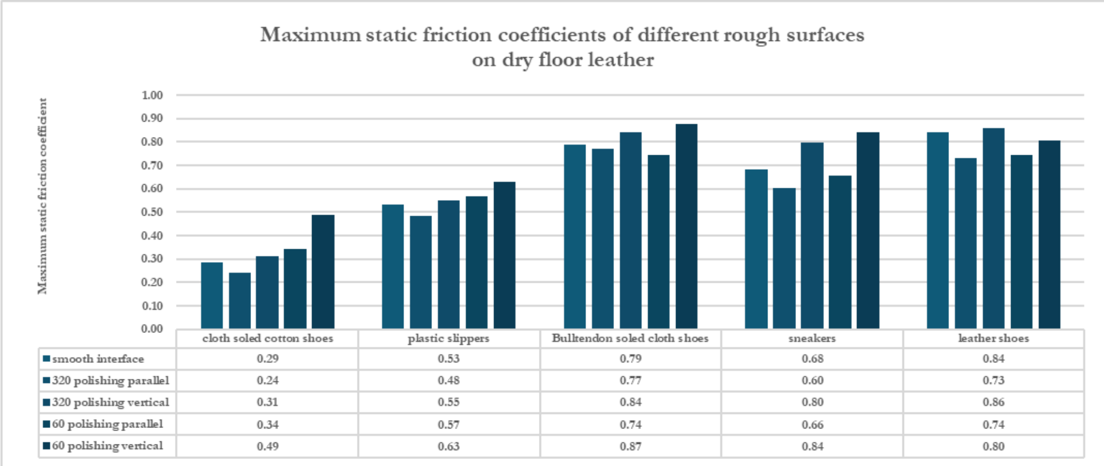
 Smooth floor leather without polishing	 Rough floor leather 320 grit sandpaper polishing	 Rough floor leather 60 grit sandpaper polishing

Figure 8: Microscopic characteristics of floor leather with different roughness

4.2.2 Different polishing directions

Polish sandpaper in the same fixed direction, applying frictional force along or perpendicular to the polishing direction. Obtain different friction coefficients in the same or perpendicular direction as the scratch.

4.2.3 Maximum friction coefficient of different rough surfaces on dry floor leather



	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 polishing parallel	0.24	0.48	0.77	0.60	0.73
320 polishing vertical	0.31	0.55	0.84	0.80	0.86
60 polishing parallel	0.34	0.57	0.74	0.66	0.74
60 polishing vertical	0.49	0.63	0.87	0.84	0.80

Figure 9: Maximum static friction coefficients of different rough surfaces on dry floor leather

Through experimental data analysis, it can be concluded that:

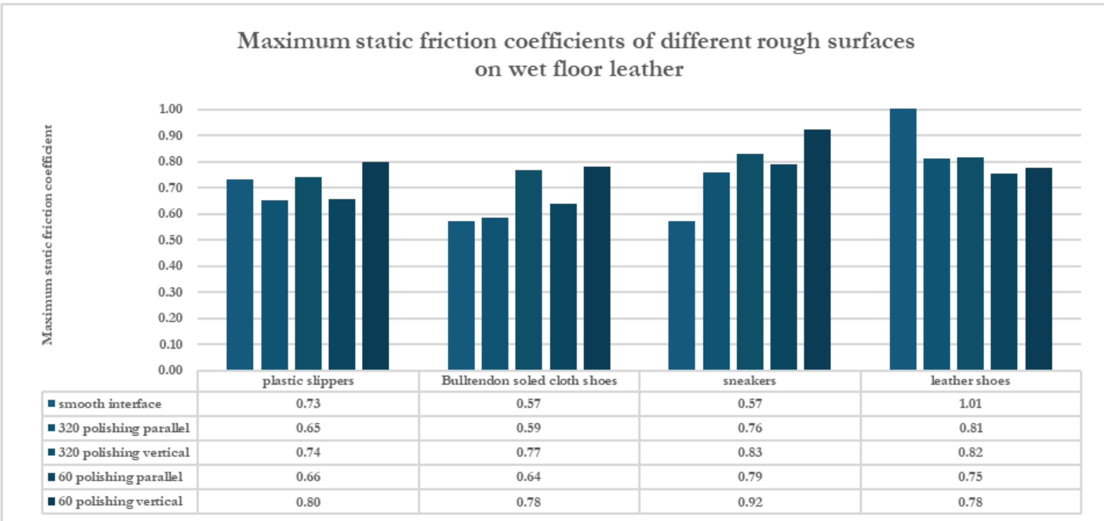
1) The change in surface roughness of the test surface will directly affect the change in friction coefficient between two identical materials.

2) The effect of different roughness on the maximum static friction coefficient is different. For most of the validated materials, the friction coefficient of the rough surface is higher in the direction perpendicular to the abrasion mark.

3) Under the same roughness, the friction coefficient in the direction perpendicular to the abrasion is greater than that in the same direction as the abrasion.

4) Grinding marks may not necessarily increase the maximum static friction coefficient. Applying force in the same direction as the scratch may reduce the maximum static friction coefficient of the material.

4.2.4 Maximum friction coefficient of different rough surfaces on wet floor leather



	plastic slippers	Bulltendon soled cloth shoes	sneakers	leather shoes
smooth interface	0.73	0.57	0.57	1.01
320 polishing parallel	0.65	0.59	0.76	0.81
320 polishing vertical	0.74	0.77	0.83	0.82
60 polishing parallel	0.66	0.64	0.79	0.75
60 polishing vertical	0.80	0.78	0.92	0.78

Figure 10: Maximum static friction coefficients of different

rough surfaces on wet floor leather

On wet test surfaces, most materials can exhibit similar phenomena and conclusions as on dry test surfaces.

4.3 The influence of different dry and wet conditions

4.3.1 Maximum static friction coefficient under different dry or wet conditions on smooth floor leather

In the experiment, the wet and dry conditions of the test surface of the floor leather were changed by sprinkling water to verify the change in the maximum static friction coefficient on damp ground:

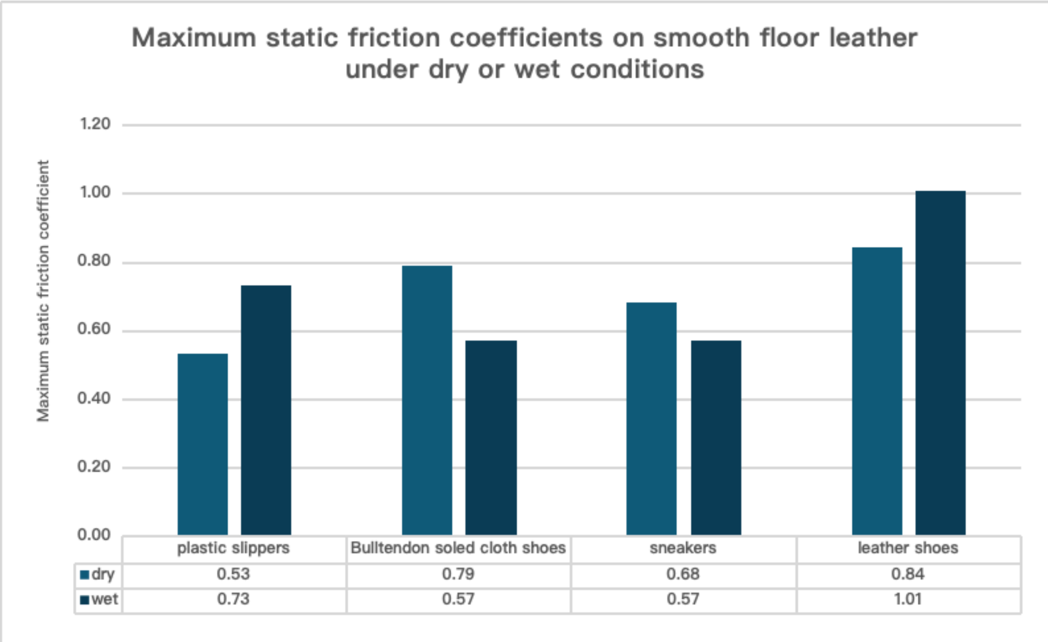


Figure 11: Maximum static friction coefficients on smooth floor leather under dry or wet conditions

On a smooth test surface, humid conditions will affect the variation of the maximum static friction coefficient. From the above figure, it can be seen that the friction coefficient of two experimental samples (Bulltendon soled cloth shoes and sneakers) decreased. The friction coefficient of the other two samples (plastic slippers and leather shoes) increased.

4.3.2 Maximum static friction coefficient under different rough surfaces and dry or wet conditions

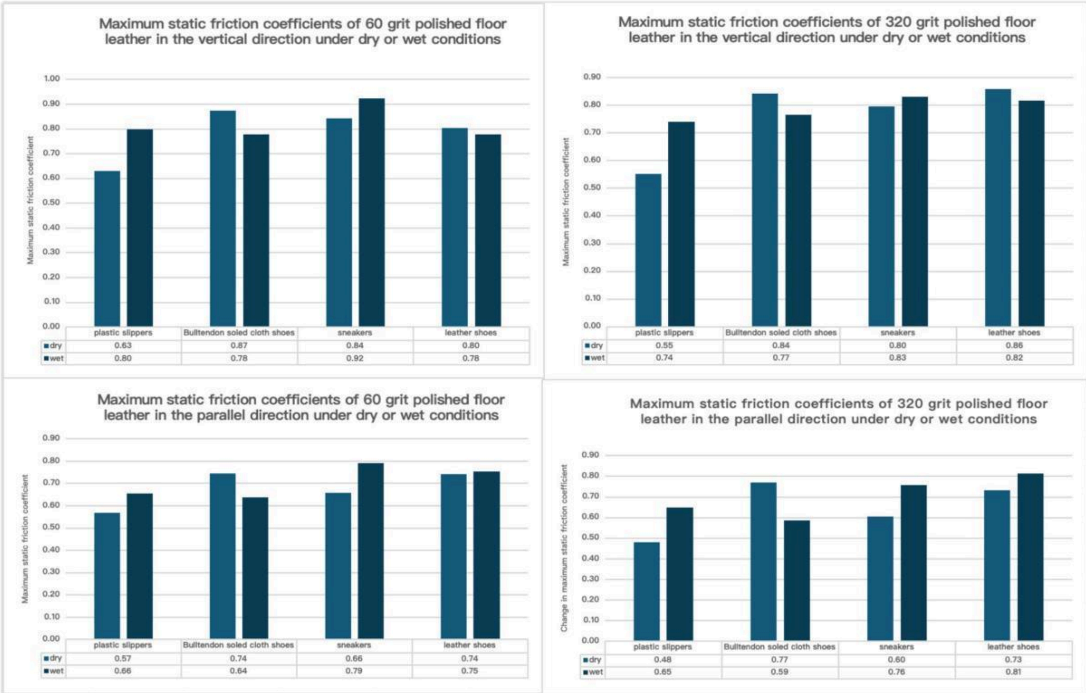


Figure 12: Maximum static friction coefficients on floor leather with different rough surfaces under dry or wet conditions

On rough surfaces, humid environments can also affect the variation of friction coefficient.However, the magnitude of the change in friction coefficient is not as large as that of a smooth plane.On the wet test surface with the same direction of abrasion, the friction coefficient of 3 out of 4 samples increased.

By researching relevant information, it is known that in some cases, damp ground can cause increased friction.It may be the result of the combined effects of multiple factors, such as the formation of liquid film and surface adhesion, the increase in contact area between liquid film and objects and ground, and the interaction between water molecules and object surfaces.

5. Conclusion and Prospect

5.1 Conclusion

This project conducted a series of experiments to study the changes in the maximum static friction coefficient of shoe soles under different roughness and dry or wet conditions.

1) The maximum static friction coefficient of different materials varies。

2)Different roughness test surfaces will affect the friction of the shoe sole.

3)The direction of the abrasion will affect the maximum static friction system.

4)Under humid conditions, some materials may significantly reduce their maximum static friction coefficient, increasing the risk of slippery falls.

5.2 Recommended measure

Based on experiments, data analysis, and conclusions, the following measures can be taken to reduce the risk of slippage:

1) Choose flooring or sole materials with good anti-skid performance.

2) Increase the roughness of the ground material and control the direction of roughness marks to be perpendicular to the walking direction.

3) Avoid slippery ground materials.

5.3 Subsequent research

Will there be different changes in friction force under different humidity conditions.?What is the anti-skid performance of other ground materials?

5.4 Outlook

Based on research analysis and conclusions, it is hoped that by improving the design, quality, and performance of ground and sole materials, the anti-skid and safety properties can be enhanced, while also being aesthetically pleasing, practical, and economical.To avoid slipping, falls, injuries, and accidents, reduce social costs, minimize medical expenses, compensation amounts, and physical and mental trauma caused by slipping.Promote the market development of ground materials and shoe sole materials, and promote the prosperity of related industries.Enhance social services and sense of responsibility, making the world more environmentally friendly, safe, comfortable, and beautiful.

6. References

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Appendix

1.Experimental data record table:

SN	condition				Dumbbell pressure(N)	Shoe pressure(N)	Maximum static friction force(N)										friction (average value)(N)	coefficient of friction
	shoe	dry or wet	Test surface to be tested	Grinding direction			1	2	3	4	5	6	7	8	9	10		
	cloth soled cotton shoes	dry	smooth interface	NA	19.85	1.42	6.08	5.43	6.20	6.24	6.55	6.36	6.20	5.33	6.15	6.32	6.07	0.29
	cloth soled cotton shoes	dry	320 polishing	parallel	19.85	1.42	5.32	5.15	5.14	5.11	5.13	5.14	5.24	5.08	5.20	5.03	5.15	0.24
	cloth soled cotton shoes	dry	320 polishing	vertical	19.85	1.42	7.21	6.45	6.74	6.49	6.36	6.25	7.31	6.30	6.68	6.58	6.64	0.31
	cloth soled cotton shoes	dry	60 polishing	parallel	19.85	1.42	7.22	7.15	7.19	7.41	7.38	7.03	7.11	7.28	7.12	7.58	7.25	0.34
	cloth soled cotton shoes	dry	60 polishing	vertical	19.85	1.42	11.74	11.53	9.72	9.16	10.30	9.41	11.82	11.73	9.65	9.17	10.42	0.49
	plastic slippers	dry	smooth interface	NA	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
	plastic slippers	dry	320 polishing	parallel	19.85	1.07	10.97	9.34	9.20	10.88	10.28	10.45	10.37	9.47	9.36	10.87	10.08	0.48
	plastic slippers	dry	320 polishing	vertical	19.85	1.07	12.68	11.38	11.28	11.46	11.29	11.19	12.45	11.39	11.12	11.27	11.55	0.55
	plastic slippers	dry	60 polishing	parallel	19.85	1.07	12.88	11.22	12.56	11.58	10.88	10.64	13.17	11.50	12.72	11.67	11.88	0.57
	plastic slippers	dry	60 polishing	vertical	19.85	1.07	13.79	13.16	12.84	13.33	13.26	12.68	13.76	13.29	12.84	13.10	13.20	0.63
	Bull tendon soled cloth shoes	dry	smooth interface	NA	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
	Bull tendon soled cloth shoes	dry	320 polishing	parallel	19.85	1.63	16.26	16.41	17.20	16.84	16.72	16.08	15.87	16.10	16.97	17.01	16.55	0.77
	Bull tendon soled cloth shoes	dry	320 polishing	vertical	19.85	1.63	18.28	18.07	18.32	17.96	17.27	18.00	18.23	17.92	18.52	18.27	18.08	0.84
	Bull tendon soled cloth shoes	dry	60 polishing	parallel	19.85	1.63	15.51	15.56	16.26	16.66	15.46	16.51	15.47	15.88	16.29	16.35	15.99	0.74
	Bull tendon soled cloth shoes	dry	60 polishing	vertical	19.85	1.63	18.71	18.90	18.64	19.27	18.36	19.08	18.45	18.81	18.88	18.85	18.79	0.87
	sneakers	dry	smooth interface	NA	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
	sneakers	dry	320 polishing	parallel	19.85	3.67	14.18	14.01	14.32	14.22	14.85	14.31	13.98	14.00	14.29	13.94	14.21	0.60
	sneakers	dry	320 polishing	vertical	19.85	3.67	18.67	19.04	18.72	18.77	18.61	17.85	18.66	19.34	18.67	18.79	18.71	0.80
	sneakers	dry	60 polishing	parallel	19.85	3.67	15.14	15.63	15.53	15.19	15.97	15.20	15.19	15.96	15.68	15.50	15.46	0.66
	sneakers	dry	60 polishing	vertical	19.85	3.67	19.73	19.76	19.73	19.71	20.44	20.20	20.05	19.36	19.36	19.68	19.80	0.84
	leather shoes	dry	smooth interface	NA	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
	leather shoes	dry	320 polishing	parallel	19.85	3.73	17.26	17.30	17.11	17.23	17.42	17.65	16.96	17.04	17.14	17.54	17.27	0.73
	leather shoes	dry	320 polishing	vertical	19.85	3.73	20.97	20.42	20.04	19.81	20.07	19.86	21.15	20.97	20.47	19.44	20.28	0.86
	leather shoes	dry	60 polishing	parallel	19.85	3.73	18.19	17.56	17.55	17.11	16.87	17.06	18.20	17.70	17.99	16.90	17.51	0.74
	leather shoes	dry	60 polishing	vertical	19.85	3.73	19.17	18.73	18.88	18.96	19.55	19.57	19.10	18.76	18.62	18.51	18.98	0.80
	cloth soled cotton shoes	wet	smooth interface	NA														
	cloth soled cotton shoes	wet	320 polishing	parallel														
	cloth soled cotton shoes	wet	320 polishing	vertical														
	cloth soled cotton shoes	wet	60 polishing	parallel														
	cloth soled cotton shoes	wet	60 polishing	vertical														
	plastic slippers	wet	smooth interface	NA	19.85	1.07	15.09	15.92	14.57	15.74	15.10	15.04	14.95	16.21	14.51	15.93	15.31	0.73
	plastic slippers	wet	320 polishing	parallel	19.85	1.07	13.27	14.10	12.89	13.97	13.62	13.73	13.23	14.32	12.78	14.06	13.60	0.65
	plastic slippers	wet	320 polishing	vertical	19.85	1.07	16.04	16.33	14.93	14.91	15.17	15.13	16.35	16.38	15.15	14.56	15.49	0.74
	plastic slippers	wet	60 polishing	parallel	19.85	1.07	14.39	13.58	13.32	13.26	14.08	14.19	14.35	13.70	13.44	13.03	13.73	0.66
	plastic slippers	wet	60 polishing	vertical	19.85	1.07	16.71	16.49	16.33	17.14	16.71	16.76	17.03	16.66	16.44	16.82	16.71	0.80
	Bull tendon soled cloth shoes	wet	smooth interface	NA	19.85	1.63	12.51	11.63	12.47	12.17	12.51	12.68	12.34	11.87	12.31	12.09	12.26	0.57
	Bull tendon soled cloth shoes	wet	320 polishing	parallel	19.85	1.63	12.30	12.93	11.20	13.51	13.60	12.50	12.14	12.97	11.42	13.59	12.62	0.59
	Bull tendon soled cloth shoes	wet	320 polishing	vertical	19.85	1.63	16.92	16.13	16.30	16.35	16.50	16.23	16.95	15.84	16.57	16.69	16.46	0.77
	Bull tendon soled cloth shoes	wet	60 polishing	parallel	19.85	1.63	13.49	14.16	14.18	12.17	14.66	14.49	13.77	13.81	14.25	12.20	13.72	0.64
	Bull tendon soled cloth shoes	wet	60 polishing	vertical	19.85	1.63	16.84	16.90	16.41	17.28	16.09	16.68	17.00	16.87	16.07	17.26	16.74	0.78
	sneakers	wet	smooth interface	NA	19.85	3.67	13.61	12.98	13.21	14.41	13.63	13.38	13.65	12.70	12.91	14.33	13.48	0.57
	sneakers	wet	320 polishing	parallel	19.85	3.67	16.79	18.07	17.57	18.62	18.35	17.93	17.16	18.11	17.20	18.42	17.82	0.76
	sneakers	wet	320 polishing	vertical	19.85	3.67	19.16	19.92	19.65	19.41	19.56	19.38	19.27	19.68	19.85	19.27	19.55	0.83
	sneakers	wet	60 polishing	parallel	19.85	3.67	18.58	18.65	18.48	19.17	18.04	17.97	18.44	18.49	18.78	19.30	18.59	0.79
	sneakers	wet	60 polishing	vertical	19.85	3.67	22.01	20.70	22.73	21.66	21.10	21.98	22.26	20.94	22.36	21.19	21.69	0.92
	leather shoes	wet	smooth interface	NA	19.85	3.73	24.23	23.77	23.54	23.67	24.06	23.38	24.18	23.48	24.12	24.06	23.85	1.01
	leather shoes	wet	320 polishing	parallel	19.85	3.73	18.74	19.05	19.85	19.08	19.28	19.10	18.34	18.58	20.18	19.32	19.19	0.81
	leather shoes	wet	320 polishing	vertical	19.85	3.73	20.23	19.47	18.57	18.58	18.39	19.36	20.09	19.78	19.01	18.74	19.26	0.82
	leather shoes	wet	60 polishing	parallel	19.85	3.73	17.63	17.79	17.67	17.79	18.10	17.17	17.80	18.00	17.85	18.23	17.80	0.75
	leather shoes	wet	60 polishing	vertical	19.85	3.73	18.37	17.69	17.89	18.66	18.94	19.55	18.58	17.68	17.73	18.22	18.33	0.78

Comments to Authors

This manuscript conducts a study of shoe sole friction on floor leather materials, and explores an important topic related to safety and accident prevention. Below are some comments and suggestions for improving the clarity and analysis of this research:

1. In general, it is suggested to improve the consistency of the manuscript in formatting, including font style, size and line spacing, etc.
2. In Section 3.1, does the "special treatment" refer to a procedure used in this experiment? If so, please provide more details.
3. When referring to figures, the figure number should be included. For example, use "As shown in Figure 2" instead of "As shown in the above figure."
4. In Section 3.4.3, it is recommended to avoid using foreign language letters in equations.
5. Figure 5 should be presented as a table rather than a figure. Same as Figure 6.
6. In Figure 6, clarification is needed regarding the distinction between dry and wet conditions. How were these conditions identified?
7. Some figures contain text that is too small to read, particularly Figures 5, 7, 9, 10, and 12. It is suggested to enlarge the text for better readability.

Decision

A **Major Revision** is recommended before reconsideration

Decision: Revise and resubmit (major revisions needed)

Comments for author

The paper is well-thought out and the topic is interesting. Novel research has been conducted, and I commend that. I have some comments:

1. Please be sure to check the formatting (e.g., spaces after punctuation, different font sizes, etc.) and the grammar. The paper is slightly difficult to follow in some paragraphs and I think a thorough check of the language issues will improve it greatly. Also, please make sure to cite relevant research papers in-text.

2. In the abstract, please specify why floor leather has been chosen.

3. Section 1 is good and details the background well. However, I would recommend choosing better section/subsection titles that reflect the nature of the study. Throughout the paper, the subtitles/titles are not conventional and it is a bit confusing for the reader.

4. In section 2, I think it's important to mention why static coefficient of friction has been selected.

5. Section 3 is clear and I like the way it is organized. I just must comment again that improvements to the language are crucial.

6. The organization of section 4 is good. However, please mention the p-values when you talk about "significant differences". I think that your graphs are good and the results are meaningful. You have discussed the results decently; however, there are some missing instances of the implications. For instance, you have spoken about the coefficients of different soles being above 0.5; what does this mean practically?
This sentence is also unclear: "Obtain different friction coefficients in the same or perpendicular direction as the scratch"

7. The conclusion is very good at summarizing the research. No comments here.

8. Fig. 6 mentions vertical vs parallel. What does this mean? Please be explicit when using terminology, although I do understand you are talking about polishing direction.

Comments to Authors

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   Reply:I have made the necessary modifications.Please refer to the full text for the modified parts.

2. In Section 3.1, does the "special treatment" refer to a procedure used in this experiment? If so, please provide more details.

   Reply：No.I made some modifications to my expression. I hope it will be better.Please refer to section 3.1 for details on the modifications.

3. When referring to figures, the figure number should be included. For example, use "As shown in Figure 2" instead of "As shown in the above figure."

   Reply:I have made the necessary modifications.Please refer to the text above or below the Figure for the modified parts.

4. In Section 3.4.3, it is recommended to avoid using foreign language letters in equations.

   Reply:I have made the necessary modifications.Please refer to Formula 2 in Section 3.4.

5. Figure 5 should be presented as a table rather than a figure. Same as Figure 6.

   Reply:I have made the necessary modifications.Please refer to Figure 5 and Figure 6 for the modified parts.

6. In Figure 6, clarification is needed regarding the distinction between dry and wet conditions. How were these conditions identified?

   Reply:I have made the necessary modifications.Please refer to section 3.5 for details on the modifications.

7. Some figures contain text that is too small to read, particularly Figures 5, 7, 9, 10, and 12. It is suggested to enlarge the text for better readability.

Reply:I have made the necessary modifications.It's clearer than before. I don't know if this can meet the clarity requirements.

Decision

A **Major Revision** is recommended before reconsideration

Decision: Revise and resubmit (major revisions needed)

Comments for author

The paper is well-thought out and the topic is interesting. Novel research has been conducted, and I commend that. I have some comments:

1. Please be sure to check the formatting (e.g., spaces after punctuation, different font sizes, etc.) and the grammar. The paper is slightly difficult to follow in some paragraphs and I think a thorough check of the language issues will improve it greatly. Also, please make sure to cite relevant research papers in-text.

Reply:I have made the necessary modifications.Please refer to the full text for the modified parts.

2. In the abstract, please specify why floor leather has been chosen.

Reply:I have made the necessary modifications.Please refer to the abstract section for details on the modifications

3. Section 1 is good and details the background well. However, I would recommend choosing better section/subsection titles that reflect the nature of the study. Throughout the paper, the subtitles/titles are not conventional and it is a bit confusing for the reader.

Reply:I have made the necessary modifications.Please refer to the section 1.3 for details on the modifications.Please refer to the entire text for modifications to the titles and subtitles.

4. In section 2, I think it's important to mention why static coefficient of friction has been selected.

Reply:I have made the necessary modifications.Please refer to the section 2.3 for details on the modifications.

5. Section 3 is clear and I like the way it is organized. I just must comment again that improvements to the language are crucial.

Reply:I have made some modifications.I hope there has been some progress.Please refer to the section 3 for details on the modifications.

6.The organization of section 4 is good. However, please mention the p-values when you talk about "significant differences". I think that your graphs are good and the results are meaningful. You have discussed the results decently; however, there are some missing instances of the implications. For instance, you have spoken about the coefficients of different soles being above 0.5; what does this mean practically?

This sentence is also unclear: "Obtain different friction coefficients in the same or perpendicular direction as the scratch"

Reply:I have made the necessary modifications.Please refer to the section 4.1 and section 4.2 for details on the modifications.

7.The conclusion is very good at summarizing the research. No comments here.

Reply:I have made a little modifications by adding some words.I hope this will be better.

8.Fig. 6 mentions vertical vs parallel. What does this mean? Please be explicit when using terminology, although I do understand you are talking about polishing direction.

Reply:I have made the necessary modifications.Please refer to the Figure 6 、9、10、12 for details on the modifications.

Replies to Reviewer Comments

In the caption for Figure 3, I made these changes since "quality" is too vague. In particular, you recorded the weights of each shoe.

Reply:I have revised it.Please refer to the Section 3.3.

At the beginning of Section 3.4, does each dumbbell weigh approximately 2kg, or do they both add up to approximately 2kg? Are the dumbbells of the same size? These things should be clarified and described here in Section 3.4, around where you write "two dumbbells weighing a total of approximately 2kg."

Reply:I have added these contents in Section 3.4."As shown in Figure 4, the masses 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. "

When you introduce the "positive pressure," note that this is not technically a pressure, as pressure would be the force per area. Rather, this is a force. Please use the term "force" instead of "pressure" throughout the paper.

Reply:I have revised it.

As you saw, I moved the "data sheet" section under the next section (pg. 12 in my edited document). This is because you should put this data table under the same section as the data analysis afterwards, perhaps as a "results" section, as that section is where your results ultimately are and are analyzed. Feel free to change the name of this section if you do not think this is as accurate.

Reply:I have revised it. It is under the "results" section.Please refer to the Section 4.

Right before Figure 6: While this is not often true in colloquial speech, "data" should be treated as plural in academic writing. Hence, I changed "The final data obtained **is**shown in Figure 6." -> "The final data obtained **are** shown in Figure 6."

Reply:I have revised it.Please refer to the Section 4.1.

Caption of Figure 6: When labeling figures, you don't usually need to say what type of figure it is. Hence, I removed "table of" at the beginning of the caption.

Reply:I have revised it.Please refer to the Figure 6 and Figure 5.

I added the page numbers, as they did not appear. You can just use the default footer page numbering as should be available in whatever word processing document you're using.

Reply:The page number has been added. I wonder if it might be a display issue.

Please ensure that all references have their DOIs attached. You can search for DOIs here, amongst other sources: https://search.crossref.org/

Reply:[6]and [7] are dissertations, which usually do not have a DOI, but their numbers can be obtained through CNKI. [5] has not been included yet, but it can be queried through CNKI. Others have attached their DOIs. Please refer to the Section "References".

You should add a sentence or two in Section 3.2 explaining what "320 grit" and "60 grit" mean and are referring to. In particular, what do the numbers refer to?

Reply:I have added these contents in Section 3.2."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. The higher the grit size, the finer the sandpaper. The lower the grit size, the coarser the sandpaper. "

Avoid using non-specific pronouns like "it" and "they." It might seem superfluous and redundant to repeat a noun/subject over and over again, but it is more specific, precise, and easier to follow to refer specifically to what you're referring to.

Reply:I have revised it.

Avoid using parentheses whenever possible.

Reply:I have revised it.

Please add sources (or a source) for the statistics in the first paragraph of Section 1.2. If sources have (or a source has) already been added to the references, please make sure you have in-line citations.

Reply:I have revised it.Please refer to the last sentence of the first paragraph in Section 1.2.

Please double-check that all words and symbols have been changed to English

Reply:I have revised it.

In Section 2.1, when introducing new terms, it is good practice to either bold or underline them. I have chosen to underline them, so as not to confuse them with (sub)section headings.

Reply:I have revised it.Please refer to the Section 2.1 and Section 3.4.

Wherever you use inline citations (e.g., [2]), please put them after each punctuation mark, e.g., ". [2]" rather than "[2]." I did not mark this everywhere as it happened in too many places, so do not forget to correct this!

Reply:I have revised it.

In Figure 2, please include what zoom you used for the microscope or at least put a rule/scale on the photos so the reader knows how large the grains shown are.

Reply:I have revised it."The magnification of the microscope is 200X".

When describing your experimental procedure, you should not describe it as if you're giving directions (e.g., don't say, "Measure the mass of different shoes and add two dumbbells weighing a total of approximately 2kg..."). Instead, either write it as if you are describing what you are doing or someone else is doing:

"We measure the mass of different shoes and add two dumbbells weighing a total of approximately 2kg..." OR

"The mass of different shoes are measured and two dumbbells weighing a total of approximately 2kg are added..."

The same applies in Section 5 (the conclusion), especially when making recommendations, but in this case, change to something like "should do"

Reply:I have revised it.

"Slip resistance" sounds a lot less awkward and more intuitive than "anti-skid performance." I would avoid using the phrase "anti-skip performance."

Reply:I have revised it.

The phrase "dry and wet conditions" is a bit of a mouthful, especially when used repeatedly in the paper. May I suggest sometimes replacing it with "moisture conditions" or something similar? It captures essentially the same meaning.

Reply:I have revised most of such cases in the article. I replaced it with "moisture conditions" .This expression is more effective.However, Figure 11 has not been changed. The annotation name in Figure 12 has been changed, but not in the figure. Because the experiment only divided into two situations: dry or wet. Would it be better to annotate more clearly in the figure?

Section 5 (Conclusion): It is unconventional to put these under different subsections. Rather, you should have each of these subsections be separate paragraphs. Furthermore, putting things in bullets everywhere makes things seem a bit informal and not elegant enough. I have added suggestions to try to connect things into paragraphs a bit more conventionally.

Reply:I have revised it.Please refer to the Section 5.

Section 6 (Acknowledgements): You should name the specific school you are part of: "given to me by the school" -> "given to the author by [insert school name here]"

Reply:I have revised it.Please refer to the Section 6.

The Frictional Properties of Shoe Soles on Floor Leathers

Abstract

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. This study examines the frictional interaction between shoe soles and floor leather, a waterproof, environmentally friendly, economical material with a wide range of applications. By measuring the maximum static friction force and calculating the maximum static friction coefficient of different shoe soles on floor leather 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, static friction force, static friction coefficient, floor leather, shoe soles

1 Introduction
1.1 Research Origin
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.
1.2 Preliminary Investigation
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.(Data source: Sohu.com, "Overview of Research on the Anti-slip Performance of Shoe Soles", August 20,2019,https://www.sohu.com/a/334950678_751728)

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, sloping slopes,[1][6] or numerous obstacles. Toilets, kitchens, and other slippery areas in residential buildings are also common locations for falls and injuries. 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.
1.3 Research Objectives
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.[2] This research aims to study the friction characteristics of various shoe sole materials on floor leather under different roughness and moisture conditions, and observe any trends in sole friction performance. Through a series of controlled experiments, we hope to reduce the risk of slip accidents while contributing to the development of safer, more slip-resistant footwear.
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:

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

2.2 Factors Affecting the Static Friction Coefficient

The magnitude of the static friction coefficient is influenced by various factors,[3] including the following:

- Contact surface properties: Contact surfaces of different materials have different friction properties, and so the static friction coefficient will also vary with the material.[7]
- 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.
- 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.[5]
- 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 their surface properties, 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.[4] 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.

3 Experimental Design and Data Collection

3.1 Testing the Surface Material

This experiment used floor leather as the test surface,[3] as shown in Figure 1. Floor leather is a rubber plastic product and one of the widely used flooring materials in the present day. Floor leather has good environmental protection, waterproof, and anti-slip properties, featuring a smooth surface that is easy to clean and maintain. After special treatment, floor leather can exhibit high surface hardness, strong corrosion resistance, and good wear resistance. Floor leather 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: Floor leather as test surface

3.2 Floor Leather Roughness

Electron microscopy observations reveal that the surface of floor leather is smooth. Hence, to obtain floor leather 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.[10] Additionally, the moisture conditions of the floor leather surface were changed by applying water.[2]

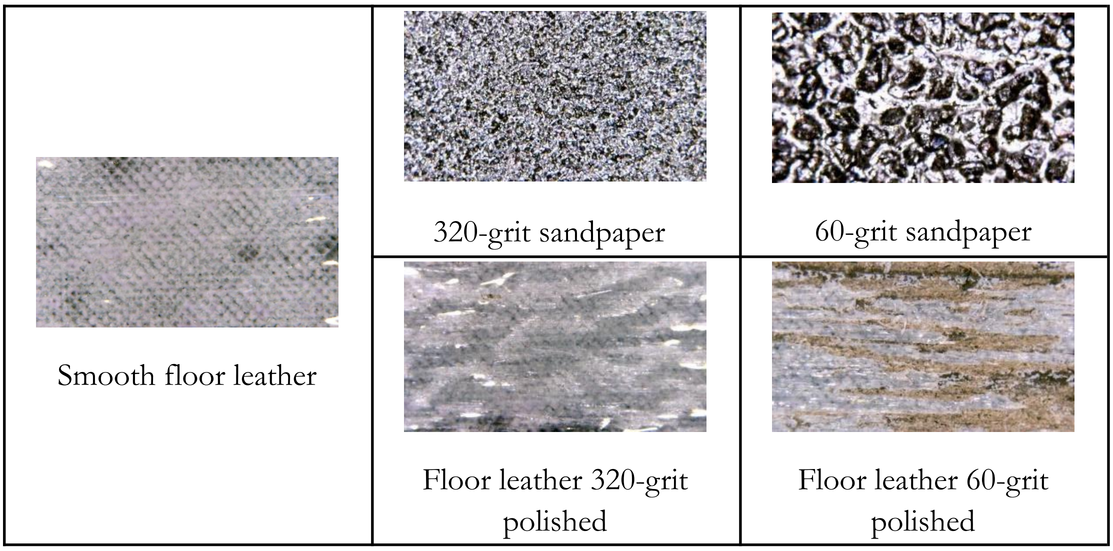


Figure 2: Various grades of sandpaper and floor leather with different roughness characteristics. Photographed using a Le Yue Professional Electron Microscope with model Z05-3. The magnification of the microscope is 200X.

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—a higher grit size corresponds to a finer sandpaper, while a lower grit size corresponds to a coarser sandpaper. As shown in Figure 2, under the microscope, we observe that the surface of the floor leather exhibits 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 floor leather. Each type of shoe exhibits different sole materials and patterns——the characteristics of each shoe are recorded separately in Figure 3.

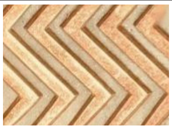
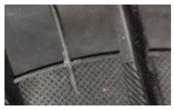
Plastic slippers	Cloth-soled cotton shoes	Bulltendon-soled cloth shoes	Sneakers	Leather shoes
				
				
				
0.109 kg	0.145 kg	0.166 kg	0.374 kg	0.381 kg

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

3.4 Experimental Procedure

Measurement method:

As shown in Figure 4, the masses 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;[4][12] KF-50 records the maximum value during the force application process 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 floor leather.

	
Friction measurement method	Dynamometer mode and display panel

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

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 Figure 5.

Condition			Force of Dumbbell (N)	Force of shoe (N)	Maximum static friction force (N)										Average friction force (N)	Coefficient of friction
Shoe	Dry and wet	Test surface to be tested			1	2	3	4	5	6	7	8	9	10		
Cloth-soled cotton shoes	Dry	Smooth interface	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	Dry	Smooth interface	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	Dry	Smooth interface	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	Dry	Smooth interface	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	Dry	Smooth interface	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

Figure 5: Experimental data record (part)

We use the following formulas:

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

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

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:

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

Analysis of slip resistance:

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 floor leather 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 floor leather 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 Figure 6.

Surface conditions for floor leather			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

Figure 6: Maximum static friction coefficients under different conditions. Parallel/Perpendicular: Direction between abrasion marks and friction force.

4.2 Maximum Static Friction Coefficient of Different Sole Materials

The maximum static friction coefficients of different shoes on dry and smooth floor leather were collected, as shown in Figure 7.

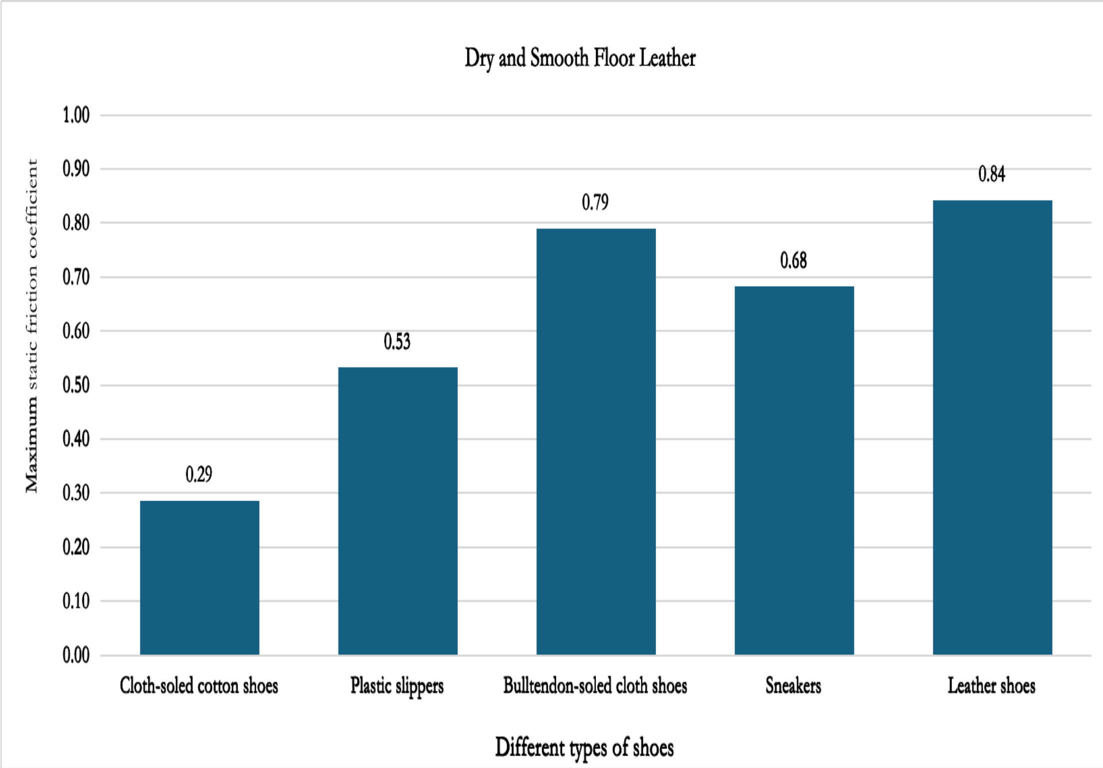


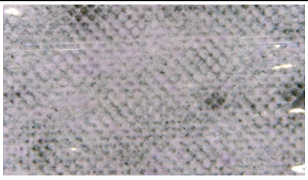
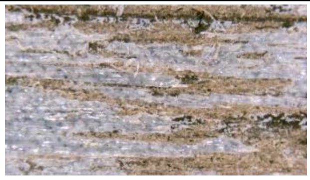
Figure 7: Maximum static friction coefficients of different shoes on dry and smooth floor leather

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.

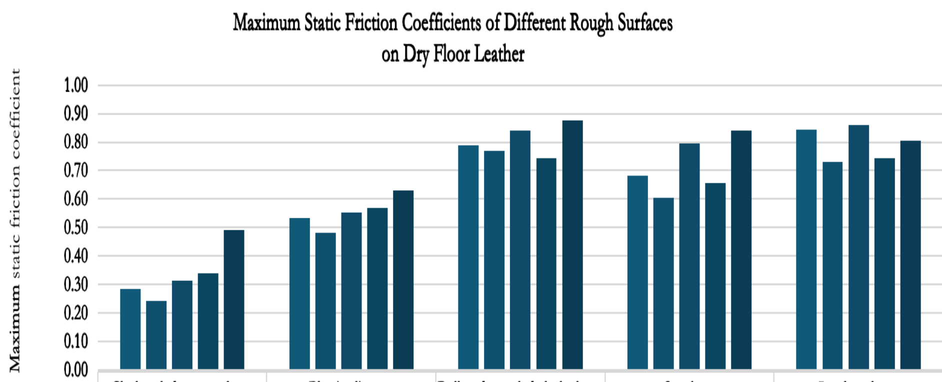
4.3 The Influence of Surface Roughness of the Test Surface on Friction Force

After polishing the floor leather with sandpaper of different grades, test surfaces of floor leather with different roughness were obtained. As shown in Figure 8, the surface of the unpolished floor leather was smooth, while the surface of the floor leather polished with 320-grit sandpaper had slight and shallow scratches. The surface of the floor leather polished with 60-grit sandpaper had deeper and coarser scratches.

Figure 8: Microscopic characteristics of floor leather with different roughness

		
Smooth floor leather without polishing	Rough floor leather 320-grit polished	Rough floor leather 60-grit polished

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——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 9: Maximum static friction coefficient of different rough surfaces on dry floor leather. Parallel/Perpendicular: Direction between abrasion marks and friction force.

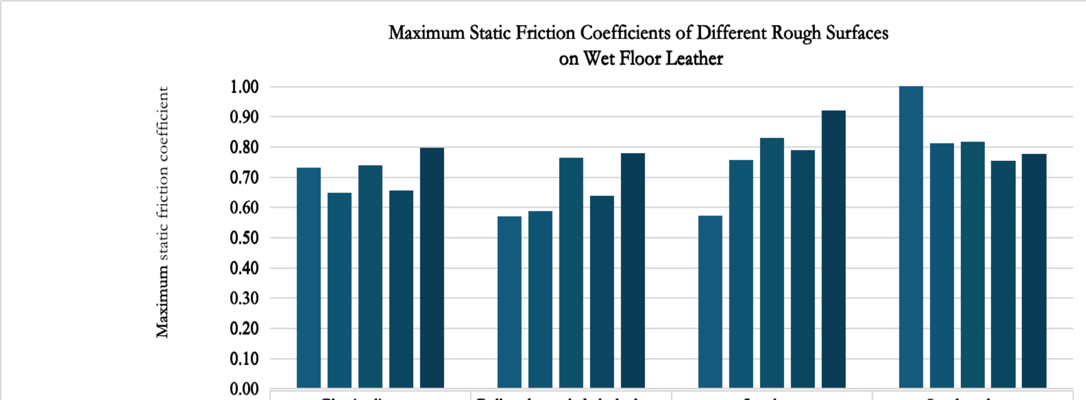
As shown in Figure 9, through experimental data analysis, it can be concluded that:

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.

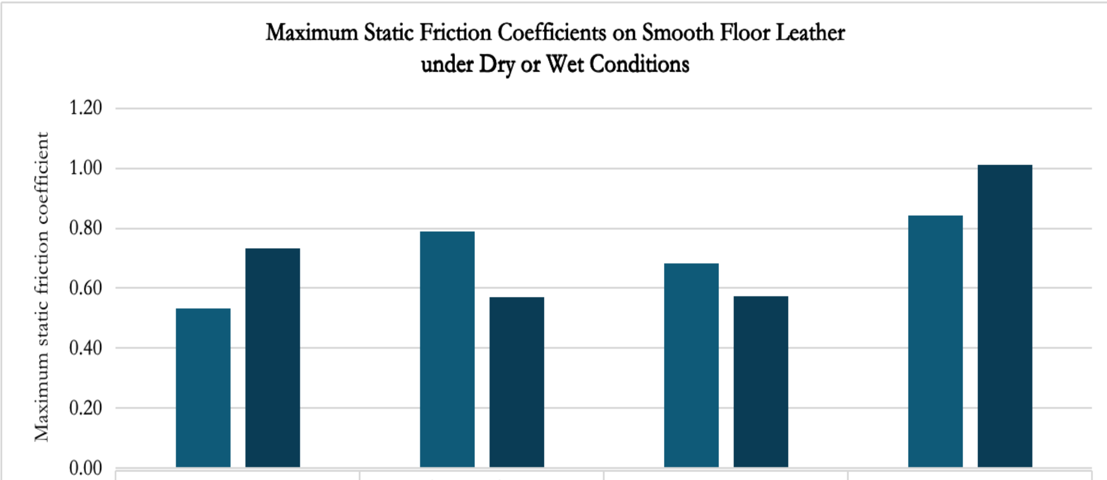


	Plastic slippers	Bulltendon-soled cloth shoes	Sneakers	Leather shoes
smooth interface	0.73	0.57	0.57	1.01
320-grit polished parallel	0.65	0.59	0.76	0.81
320-grit polished perpendicular	0.74	0.77	0.83	0.82
60-grit polished parallel	0.66	0.64	0.79	0.75
60-grit polished perpendicular	0.80	0.78	0.92	0.78

Figure 10: Maximum static friction coefficient of different rough surfaces on wet floor leather. Parallel/Perpendicular: Direction between abrasion marks and friction force.

As shown in Figure 10, on wet test surfaces, most materials exhibit similar anti-slip phenomena and conclusions as on the dry test surface. Refer to the experimental data analysis content of Figure 10 in section 4.2.

4.4 Effects of Different Dry and Wet Conditions



	Plastic slippers	Bulltendon-soled cloth shoes	Sneakers	Leather shoes
Dry	0.53	0.79	0.68	0.84
Wet	0.73	0.57	0.57	1.01

Figure 11: Maximum static friction coefficient s on smooth floor leather under dry or wet conditions

In the experiment, the moisture conditions of the floor leather test surface were changed by sprinkling water to verify 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. As shown in Figure 11, 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 12: Maximum static friction coefficient under different rough surfaces and moisture conditions. Parallel/Perpendicular: Direction between abrasion marks and friction force.

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,[8] as shown in Figure 12.

Prior research has shown that in some cases, wet ground can lead to increased friction.[9] 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.[12][13]

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, 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 the changes in friction force under varying moisture conditions to better understand how moisture affects slip resistance. Additionally, investigating how the friction force varies more precisely with the direction of rough marks and walking direction at different angles—such as in multiple or irregular directions—could provide deeper insights into real-world walking conditions. Furthermore, exploring the slip resistance of other ground materials would help expand the results of this study to more environments.

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; evaluating anti-slip performance in different risk areas can help guide material selection while promoting market development of 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 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 embracing these innovations, we hope to create a smarter, more environmentally friendly, and safer world.

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