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Determination of The Static Friction Coefficient of Some Materials Used for Anti-slip Safety with ANOVA

Murat Diker[1], Bulent Cakmak[2], Engin Ergul [3*]

[1]Yasar University, Vocational School, Department of Property Protection and Security, 35100, Izmir, TURKEY
[2]Ege University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, 35100, Izmir, TURKEY
[3]Dokuz Eylul University, Izmir Vocational School, Department of Machinery and Metal Technologies, 35380, Izmir, TURKEY

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Abstract
The surface conditions of ground surface coatings, which are widely used in working environments exposed to various pollutants, were evaluated from a safety perspective. In this work, static friction coefficient of some floor coverings exposed to different pollutants for various reasons and some shoe sole materials that are widely used in working environments were determined. The interaction between soil, floor, and surface contaminations were evaluated statistically. In particular, the ground surface contaminated with contaminants such as water and surface cleaners, which significantly reduce the security of the floor is studied. ANOVA results showed that the floor covering, shoe sole samples, and floor contaminants were significant for each variable of the friction coefficient (μ) ($p < 0.05$). It was determined that the correlation between two factors and three factors between a floor covering, shoe sole samples, and floor surface contaminant conditions significantly affects the friction coefficient (μ). Seven floor samples used in the study were evaluated in terms of safety classification and the results ranking from the highest to the lowest were "Granite ceramic with a glossy surface", "PVC linoleum coating", "Laminated wood parquet", "Matte surface ceramic", "Rough surfaced ceramic", "Matte, rough, non-slip, fireproof ceramic, "Natural granite stone (processed)". When the effect of floor samples on the static friction coefficient is examined, safe ones according to the DIN 51097 standards for all working areas; it has been determined that "PVC linoleum coating" ($\bar{X} = 0.52$), "Laminated wooden parquet" ($\bar{X} = 0.48$), "Granite ceramic with a glossy surface" ($\bar{X} = 0.46$).

Key Words
"Fall injuries, fall prevention, occupational health and safety, industrial ergonomics"

***Sorumlu Yazar:** engin.ergul@deu.edu.tr*

1. Introduction

Slip, trips, and falls cause a significant portion of injuries in the workplace. Slipping is considered a major factor leading to falls and injuries. The primary risk factor for slip accidents is undoubtedly reduced friction between shoes and underfoot surfaces. Secondary risk factors are, for example, poor postural control, aging, diabetes, alcohol intake, and use of anxiety medication drugs (Grönqvist & Hirvonen, 1995). Many factors contribute to the mechanism of a slip, including surface conditions like dry versus wet, ice, grease, particulates, etc. floor surface characteristics, shoes, and biomechanics of gait. Feasible corrective actions include changing the work environment, eliminating hazardous conditions, and providing protective devices. Slip resistance is usually determined by the coefficient of friction between interacting surfaces (McVay & Redfern b, 1994). There are numerous machines and methods for measuring the coefficient of friction between shoes and upholstery. However, there is little agreement on how to accurately measure friction with a machine, as the parameters governing walking are constantly changing as the pedestrian moves, and some workers prefer to evaluate friction or pedestrian slip resistance. Several German tests using this principle are based on an inclined ramp. DIN 51097 is a test for evaluating the suitability of flooring materials for use in wet-footed areas and DIN 51130 is a similar test for evaluating flooring materials for use in work environments heavily contaminated with oil (James, 1999).

The friction properties of shoe heels and soles are central to preventing slips and falls (Leclercq, 1999). ANOVA, (Ergul & Kurt, 2021; Kurt, Oduncuoglu, et al., 2018; Kurt, Yilmaz, et al., 2018; Kurt & Oduncuoglu, 2015) is a nice way to measure significant degree. In recent studies, most efforts in preventing slips and falls have centered on work surfaces. The purposes of Chang et al., (2001) are to summarize our understanding of friction measurement related to slipperiness assessment of shoe and floor interfaces and to define test conditions based on biomechanical observations. They said that the test conditions should satisfy some conditions, depending on the test methods. The normal force was built up at least 10 kN s^{-1} for the whole-shoe testing devices. The normal pressure and sliding velocity at the interface were between 0.2 and 1.0 MPa, and between zero and 1.0 m s^{-1}, respectively. The times of contact before and during the coefficient of friction (COF) computations were between zero and 600 ms. Gao and Abeysekera, (2002) emphasized that in addition to thermal insulation in the development of shoes for use in cold climates, the prevention of slipping and falling danger by improving the anti-slip feature and wearability should be priorities. McGorry et al., (2007) report on the development and evaluation of a measure of slip distance based on variables derived from the signal of a heel-mounted accelerometer. In their work twenty-one participants walked on a laboratory runway under several surface slipperiness conditions. Their analysis of variance showed significant effects on slip distance (no-slip, micro-slip, and slide), and walking speed (1.52, 1.78, and 2.13 m/s). Regression analysis indicated a reasonably strong relationship, $R^2 = 0.511$, between slip distance and deceleration time. The analysis of the heel-mounted accelerometer output has demonstrated the potential of this approach as an adjunct human-centered measure in the evaluation of surface slipperiness. Liu et al., (2010) reported that the floors with grooves perpendicular to the friction measurement direction had the highest friction coefficients among the floor conditions in both the wet and glycerol-contaminated conditions except for the wet/flat sole/10° condition. The differences among fingertip, palm, and foot in the perceived floor slipperiness were not statistically different. The regression analysis results of Li, Yu and Zhang, (2011) Li indicated that the floor roughness parameter Ra is a better predictor in predicting both the perceived floor roughness and perceived floor slipperiness than the COF of the floor. Li, Meng, and Zhang (2014) stated that on wet surfaces, solid particles diminish the squeeze film effects between the footwear pad and the floor and the hardness of the footwear pad has a lesser impact on the COF. Since the COF values of natural stones decrease in a wet environment, the risk of slipping is high, especially on polished surfaces. Çoşkun et al., (2019) have determined that it is safer to use on aged surfaces in areas where one can walk barefoot in a wet environment. Footwear with better slip resistance can dramatically reduce the risk of fall-related injuries in the winter (Bagheri et al., 2021).

This study provides the determination of static COF for some floor coverings exposed to different pollutants for various reasons and some shoe sole materials that are widely used in working environments. Most of this work is about occupational accidents or prevention.

2. Materials and Methods

2.1. Materials

Different materials are used as coating materials on floors where employees walk around and perform business activities in open and closed working environments. In this study, seven different types of floor covering materials with different structural features, which are widely used in the working environment in the market, are used. The letter (Z) is used to indicate that the variable belongs to the "floor covering". In Table 1, these materials are coded randomly from Z1 to Z7.

Table 1. Coding of floor covering materials

Code	Floor
Z1	Rough-surfaced ceramic
Z2	Matt surface ceramic
Z3	Laminated wood parquet
Z4	PVC linoleum coating
Z5	Matte, rough, non-slip, fireproof ceramic
Z6	Bright surface granite ceramic
Z7	Natural granite stone (processed)

Shoe sole samples with 5 different structural features, which are widely used in the market, were used. The letter (T) is used to indicate that the variable belongs to the "shoe sole". In Table 2, these examples are coded randomly from T1 to T5.

Table 2. Coding of sole materials

Code	Sole
T1	Leather sole
T2	Symmetrical knurled rubber sole
T3	Thick rubber sole with asymmetric relief surface
T4	Serrated asymmetrical rubber soles
T5	Polished surface rubber sole

In the study, dry ground and two different pollutants frequently encountered in working environments were used. The letter (K) is used to express the pollutant variable. In Table 3, these examples are coded randomly from T1 to T5. The K0 code is used in the expression of dry ground. Tap water K1 was chosen as the first pollutant, and K2 was a chemical surface cleaner. The chemical surface cleaning material contains deionized water, 5%-15% nonionic active substance, <5% anionic active substance, <5% sodium hydroxide, preservative, and perfume.

Table 3. Coding of pollutants

Code	Description
K0	Dry floor
K1	Wet ground (tap water)
K2	Surface cleaner materials

In Figure 1, a mechanical contact system between the ground and the sole has been created using pollutants.

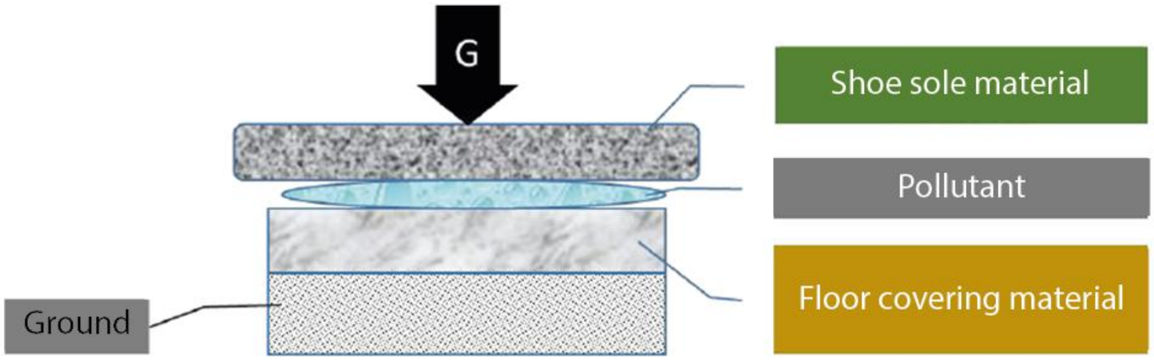

Figure 1. A system consisting of a base, pollutant, and ground independent variables

2.2. Test Methods for Determining the Coefficient of Friction

An experimental setup was used to determine the static friction coefficient (Figure 2). The assembly consists of an actuator operating with adjustable DC current between 0-24 V and a moving platform. In the preliminary trials, the platform on which the friction system is located was moved at a forward speed corresponding to 10 V voltage. The platform works with three functions (forward-stop-backward). In the study, the floor covering material was fixed on the platform and the base material was placed on the metal cylindrical platform. The metal cylinder was connected to the dynamometer with a string and the string tension was reduced between the dynamometer and the cylinder before the movement. During the movement of the platform, the friction force was measured instantly and recorded on a dynamometer connected to the base material.

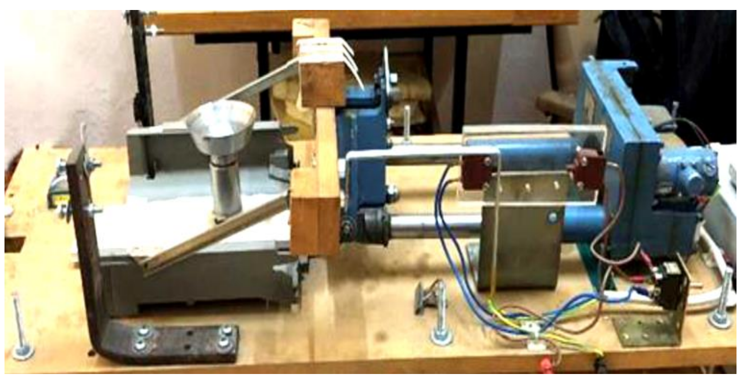

Figure 2. A view of the test methods for determining coefficient of friction

In the friction test, the average normal walking speed was predicted as 0.3 m/s for humans. During this process, the friction resistance on the sole placed in the test system was measured instantly in N (Newton) with a digital dynamometer. Each system combination was performed in a laboratory at a room temperature of 24 °C.

2.3. Statistical Analysis with ANOVA

In this study, measurements were made to measure the friction force in the horizontal plane in the prepared setup. In these statistical studies, reference values determined by international standards published in this field were used to determine which floor will be considered a safe working surface and which floor will be considered an unsafe working surface. For this study, the static friction coefficient (μ) = 0.45 was taken as the reference value, which is considered safe with low slip risk, specified in the DIN 51097 standards. The analysis of variance (ANOVA) method was used to determine how the floor, sole, and pollutant samples affect the static friction coefficient individually and together. The confidence level in this statistical analysis study (95%), and the probability error margin outside the mentioned security level (Alpha) (5%) were evaluated and the data was significant $p < 0.05$.

3. Results

As a dependent variable, static friction coefficient (μ), five different bases, and floors contaminated with contaminants (dry floor, wet floor, and surface cleaner) were determined as independent variables. Error-variance equality analysis was performed separately. In the evaluations made, it was observed that the effects of the data on the dependent variables were significant.

In this study, the safe static friction coefficient (μ = 0.45), which is accepted for floor anti-slip in the DIN 51097 Standard, is taken as the reference. The friction coefficients between the soil and base samples used in the study were compared with the reference value of the relevant standard. Variance analysis results according to the static friction coefficient dependent variable of the soil, bottom, and pollutant samples are shown in Table 4. In determining the static friction coefficient; the independent variables (floor), (sole), and (pollutant) first each individually, then in groups of two (floor * sole), (floor * pollutant), (sole * pollutant) and finally all three variables when the interaction between (floor * sole * pollutant) is evaluated; It has been observed that these interactions have a significant effect on the static friction coefficient values.

Table 4. Variance analysis results according to the static friction coefficient dependent variable of the soil, bottom, and pollutant samples

Source of variance	KT	sd	KO	F	(p)
Floor	1.722	6	.287	212.576	.000
Sole	.428	4	.107	79.294	.000
Pollutant	3.116	2	1.558	1154.139	.000
Floor * sole	1.537	24	.064	47.423	.000
Floor * pollutant	4.189	12	.349	258.554	.000
Sole * pollutant	2.791	8	.349	258.449	.000
Floor * sole * pollutant	1.944	48	.040	29.996	.000
Error	.567	420	.001		
Total	112.401	525			

Alpha =.05

ANOVA analysis was interpreted for the static friction coefficient data. According to these values, the effect of each independent variable on the static friction coefficient alone is important. In the results, it can be said that the results are similar between (floor * pollutant) and (sole * pollutant), and there is no significant difference between these pairs. A graphic showing the effect of soils and their bases on the static friction coefficients is given in Figure 3.

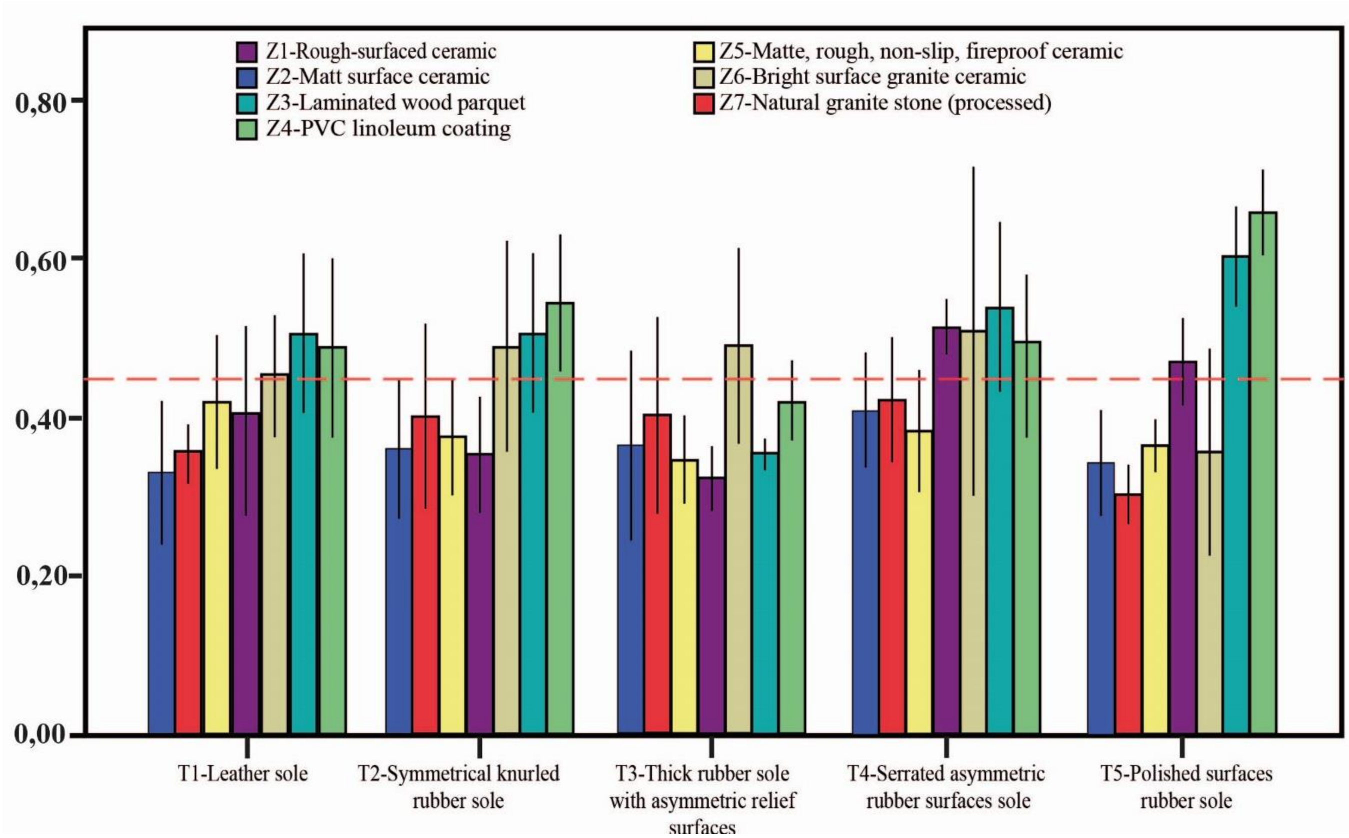

Figure 3. The effect of soils and their bases on the static friction coefficients

When the data obtained from the measurements are examined from the graph in Figure 3, each group is listed below from the low static friction coefficient value to the highest according to ($\mu = 0.45$).

- The power of the "leather floor" sample on the "laminated wooden parquet", "PVC linoleum coating" and "glossy granite ceramic" samples,
- The power of the "rubber base with symmetrical serrated surface" sample on the "PVC linoleum coating" and "glossy surface granite ceramic" samples,
- The power of the "thick rubber sole with asymmetric relief surface" sample on the "glossy surface granite ceramic" samples,
- The power of the "serrated asymmetrical rubber sole" sample on "laminated wooden parquet", "rough surface ceramic", "glossy surface granite ceramic" and "PVC linoleum coating" samples,
- The power of the "glossy rubber sole" sample on the "PVC linoleum coating", "laminated wooden parquet" and "rough surface ceramic" samples.

It was found that each floor had a significant difference in the static friction coefficient (Table 4). Since there are seven floor samples, it was determined that they should be grouped into five different sub-clusters by evaluating them according to the multiple comparison “Duncan” results to determine their effect on the static friction coefficient separately. Table 5 shows the results of the "Duncan" test made to determine which groups the average static friction coefficient dependent variable differs according to the soil variable. According to these results, "PVC linoleum coating", "Laminated wooden parquet" and "glossy surface granite ceramic" were determined as safe floors.

Table 5. The results of the “Duncan” test were conducted to determine among which groups the average static friction coefficient dependent variable differs according to the floor variable.

Static μ	**Subset**					
Floor (Z)	1	2	3	4	5	6
Z2	0.36					
Z7		0.38				
Z5		0.38				
Z1			0.41			
Z6				0.46		
Z3					0.48	
Z4						0.52

Alpha =.05

It was found that each sole differed significantly in the static friction coefficient alone in Table 4. According to these results, it was observed that the "serrated asymmetrical rubber sole" has the highest static friction coefficient and can be used safely. It was determined that other floors were below the limit value accepted as safe (Table 6).

Table 6. The results of the “Duncan” test were conducted to determine among which groups the average static friction coefficient dependent variable differs according to the sole variable.

Static μ	**Subset**			
Sole (T)	1	2	3	4
T3	0.38			
T2		0.42		
T1		0.42		
T5			0.44	
T4				0.47

Alpha =.05

Pollutants differ significantly in the static friction coefficient in Table 4. Since the number of pollutant samples is 3, it was determined that they should be grouped into three different sub-clusters by evaluating them according to the multiple comparison "Duncan" results to determine their effect on the static friction coefficient separately. According to these results, it was determined that the "Surface cleaner" variable on the static friction coefficient was unsafe, the "wet floor" independent variable was partly safer, and the "dry floor" independent variable was the safest among these three pollutants (Table 7).

Table 7. The results of the "Duncan" test were conducted to determine among which groups the average static friction coefficient dependent variable differs according to the pollutant variable.

Static μ	**Subset**		
Pollutant (K)	1	2	3
K2	0.32		
K1		0.47	
K0			0.50

Alpha =.05

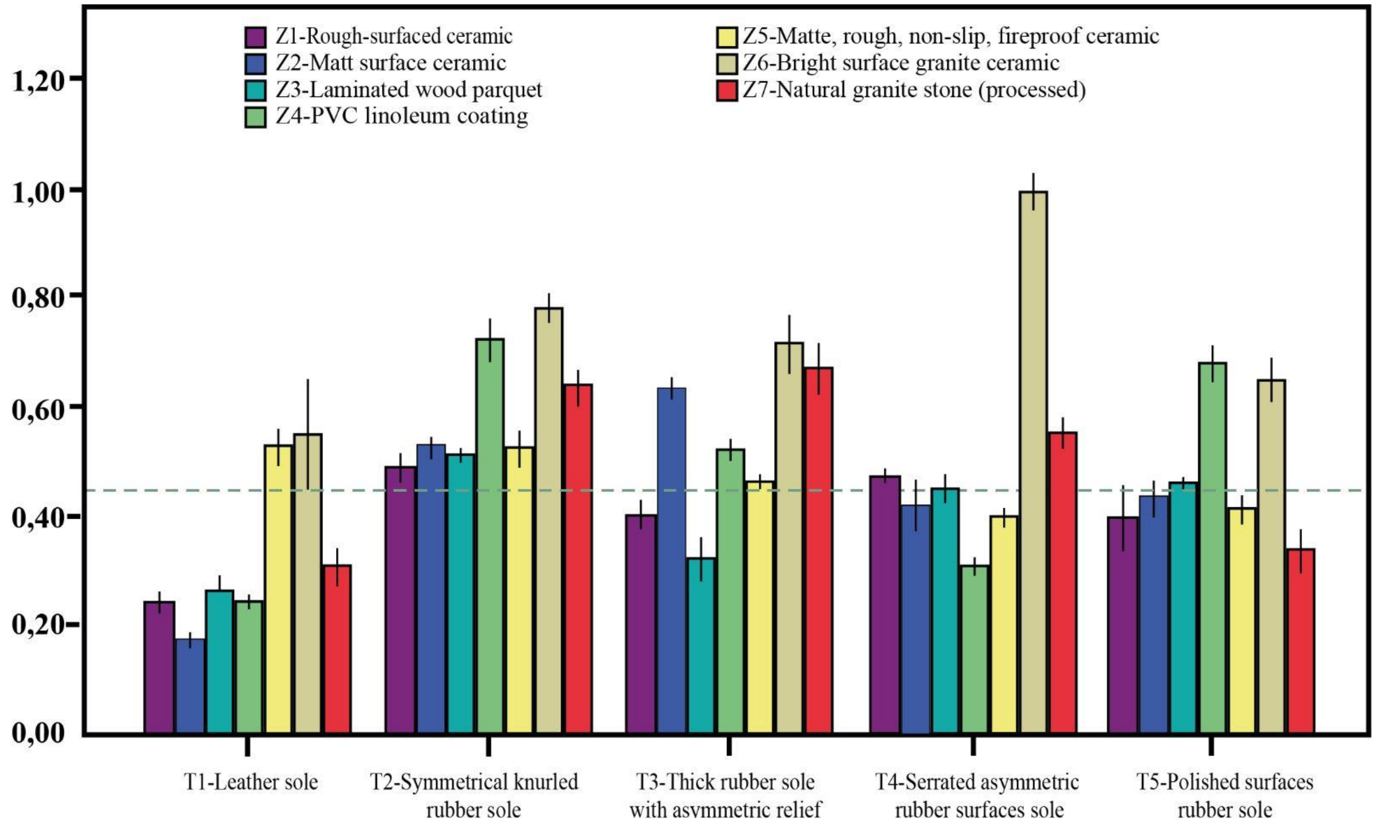

Figure 4. The effect of the interaction of dry floors and sole on the static friction coefficient

When the data obtained from the measurements are examined from the graph in Figure 4, each group is listed below from the low static friction coefficient value to the highest according to ($\mu = 0.45$).

- The power of the "leather floor" sample on the "glossy surface granite ceramic", "matte, rough, non-slip, fireproof ceramic" samples,
- The power of the "rubber base with symmetrical serrated surface" sample on the "glossy surface granite ceramic", "PVC linoleum coating", “natural granite stone (processed)”, "rough surface ceramic", "matte, rough, non-slip, fireproof ceramic", "laminated wooden parquet" and "rough surface ceramic" samples,
- The power of the "thick rubber sole with asymmetric relief surface" sample on the "glossy surface granite ceramic", “natural granite stone (processed)”, "rough surface ceramic", "PVC linoleum coating" and "matte, rough, non-slip, fireproof ceramic" samples,
- The power of the "serrated asymmetrical rubber sole" sample on "glossy surface granite ceramic", "natural granite stone (processed)", "rough surface ceramic" and "laminated wooden parquet" samples,
- The power of the "glossy rubber sole" sample on the "PVC linoleum coating", "glossy surface granite ceramic" and "laminated wooden parquet" samples.

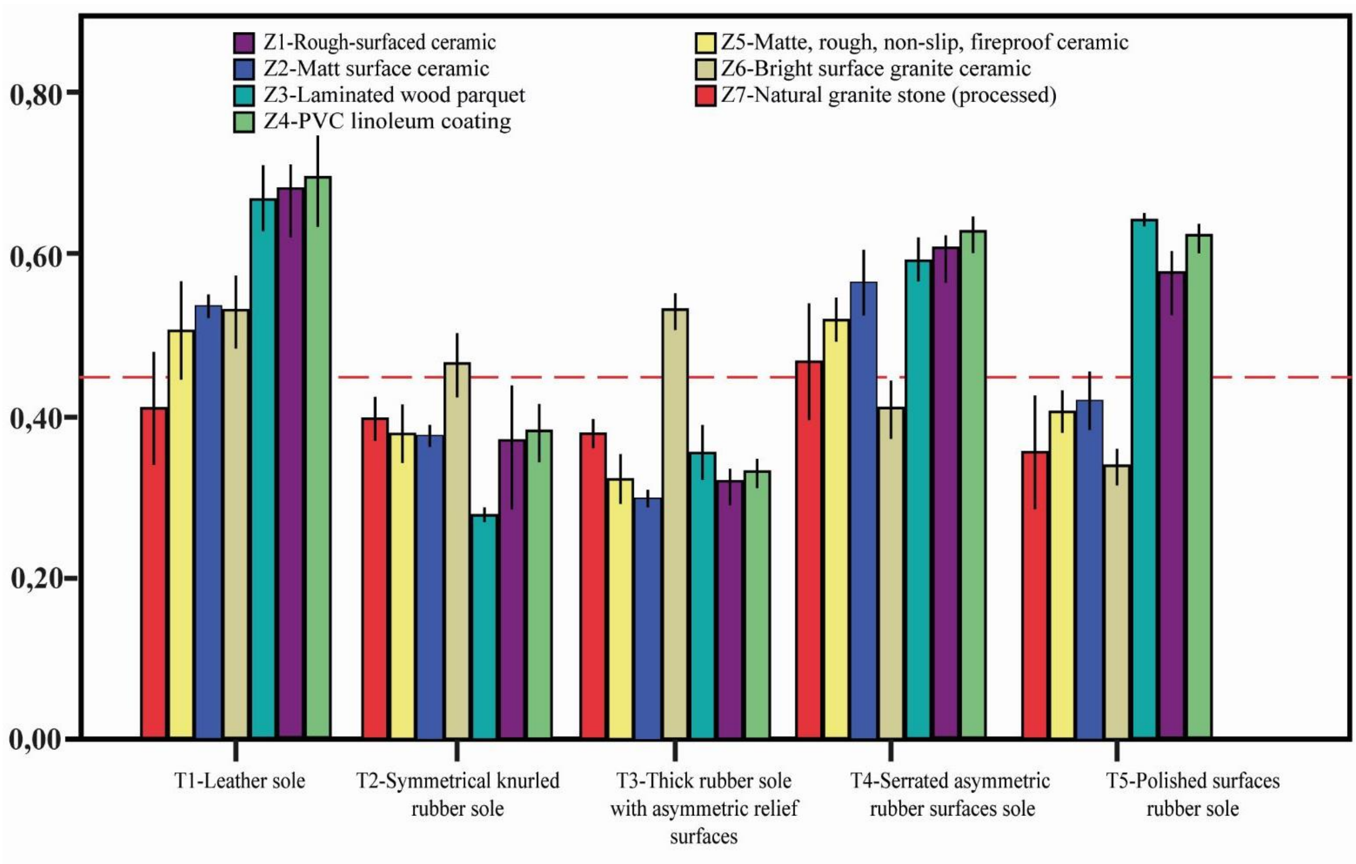

Figure 5. The effect of the interaction of wet floors and sole on the static friction coefficient

When the data obtained from the measurements are examined from the graph in Figure 5, each group is listed below from the low static friction coefficient value to the highest according to (μ = 0.45).

- The power of the "leather floor" sample on the "PVC linoleum coating", "rough surface ceramic", "laminated wooden parquet", “matte surface ceramic”, "glossy surface granite ceramic" and "matte, rough, non-slip, fireproof ceramic" samples,
- The power of the "rubber base with symmetrical serrated surface" sample on the "glossy surface granite ceramic" samples,
- The power of the "thick rubber sole with asymmetric relief surface" sample on the "glossy surface granite ceramic" samples,
- The power of the "serrated asymmetrical rubber sole" sample on "PVC linoleum coating", "rough surface ceramic", "laminated wooden parquet", “matte surface ceramic”, "matte, rough, non-slip, fireproof ceramic" and "natural granite stone (processed)" samples,
- The power of the "glossy rubber sole" sample on the "laminated wooden parquet", "PVC linoleum coating" and "rough surface ceramic" samples.

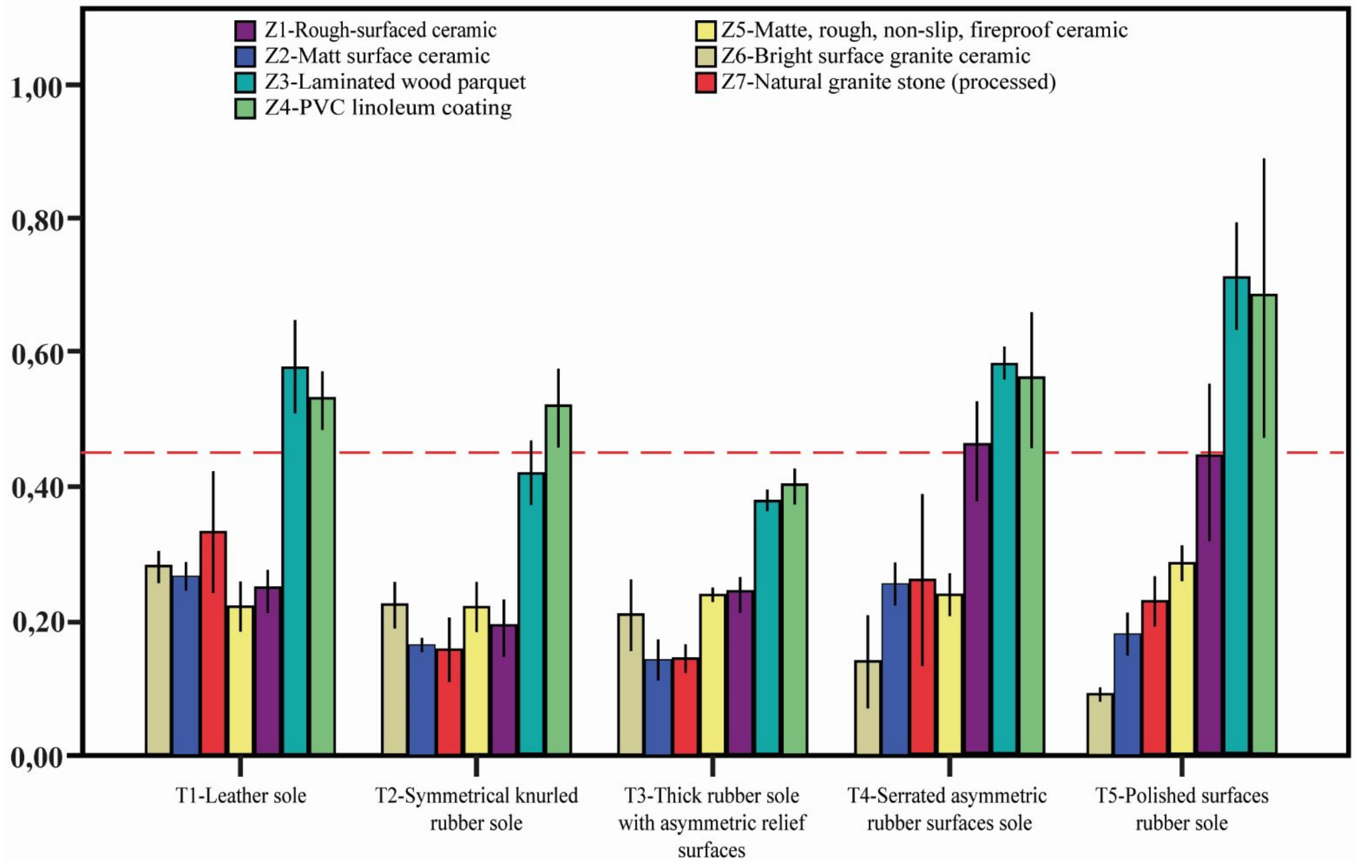

Figure 6. The effect of the interaction of the polluted floor and sole on the static friction coefficient

When the data obtained from the measurements are examined from the graph in Figure 6, each group is listed below from the low static friction coefficient value to the highest according to (μ = 0.45).

- The power of the "leather floor" sample on the "laminated wooden parquet" and "PVC linoleum coating" samples,
- The power of the "rubber base with symmetrical serrated surface" sample on the "PVC linoleum coating" samples,
- The "thick rubber sole with an asymmetric relief surface" does not affect the polluted floor
- The power of the "serrated asymmetrical rubber sole" sample on "laminated wooden parquet", "PVC linoleum coating" and "rough surface ceramic" samples,
- The power of the "glossy rubber sole" sample on the "laminated wooden parquet", "PVC linoleum coating" and "rough surface ceramic" samples.

4. Discussion

When the data of sole materials were evaluated statistically, it was determined that shoe soles differ according to their physical and structural properties. As the reason for this difference, it has been observed that the physical shape of the soles is also important in addition to the structural properties of the material from which the shoe sole is produced. According to the results obtained from the measurements, it was determined that shoes with a highly embossed asymmetric pattern in the selection of shoe soles have less adhesion on flat and smooth surfaces. The static friction (Basyigit, 2020; Gur et al., 2014; Hekimoğlu &

Hacıosmanoğlu, 2019; Pul & pul, 2019), coefficients for floor coverings were in the range of 0.36–0.52 (

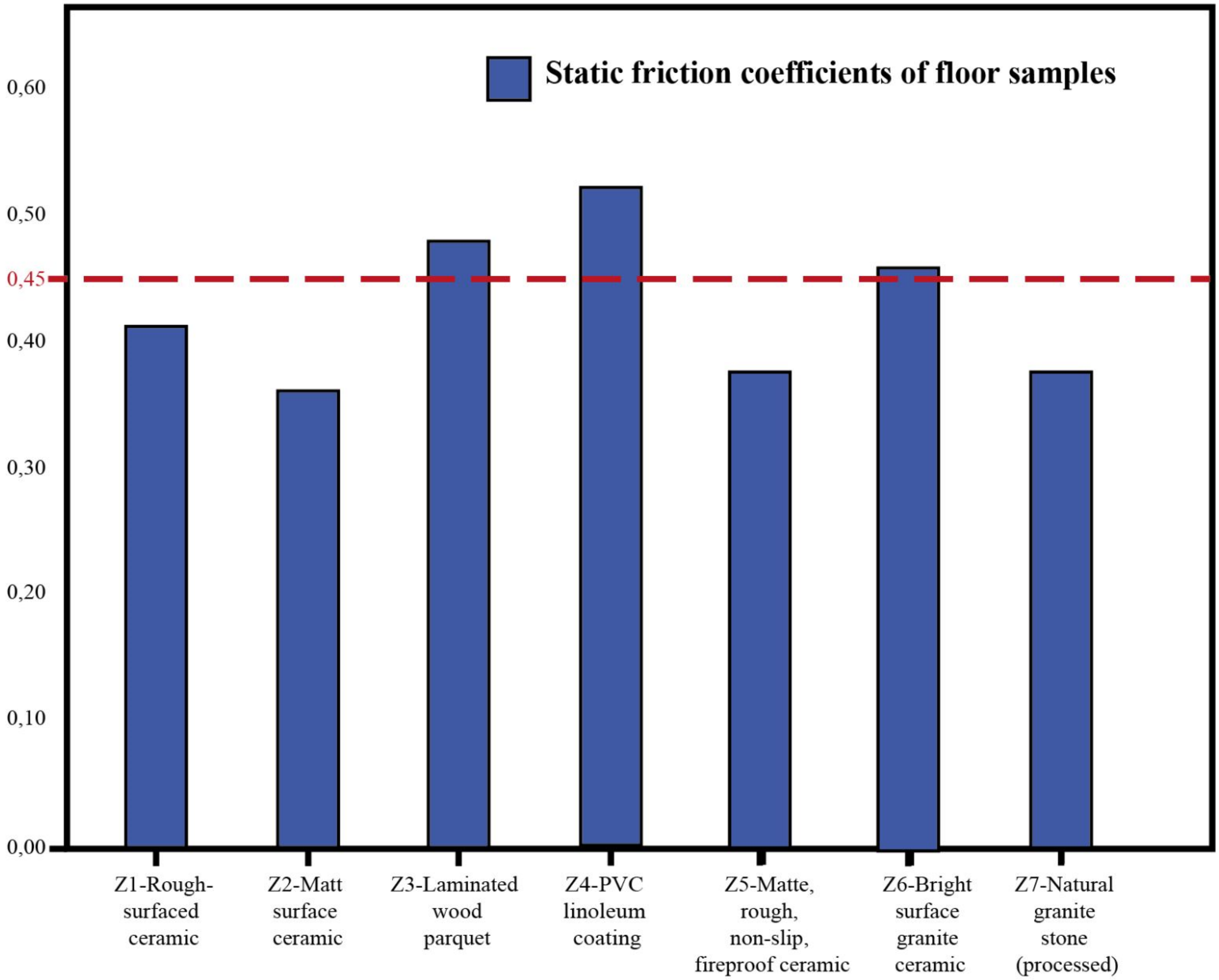

Figure 7). These values were found to be in the range of 0.17–0.60 in the study conducted by (Yu & Li, 2012).

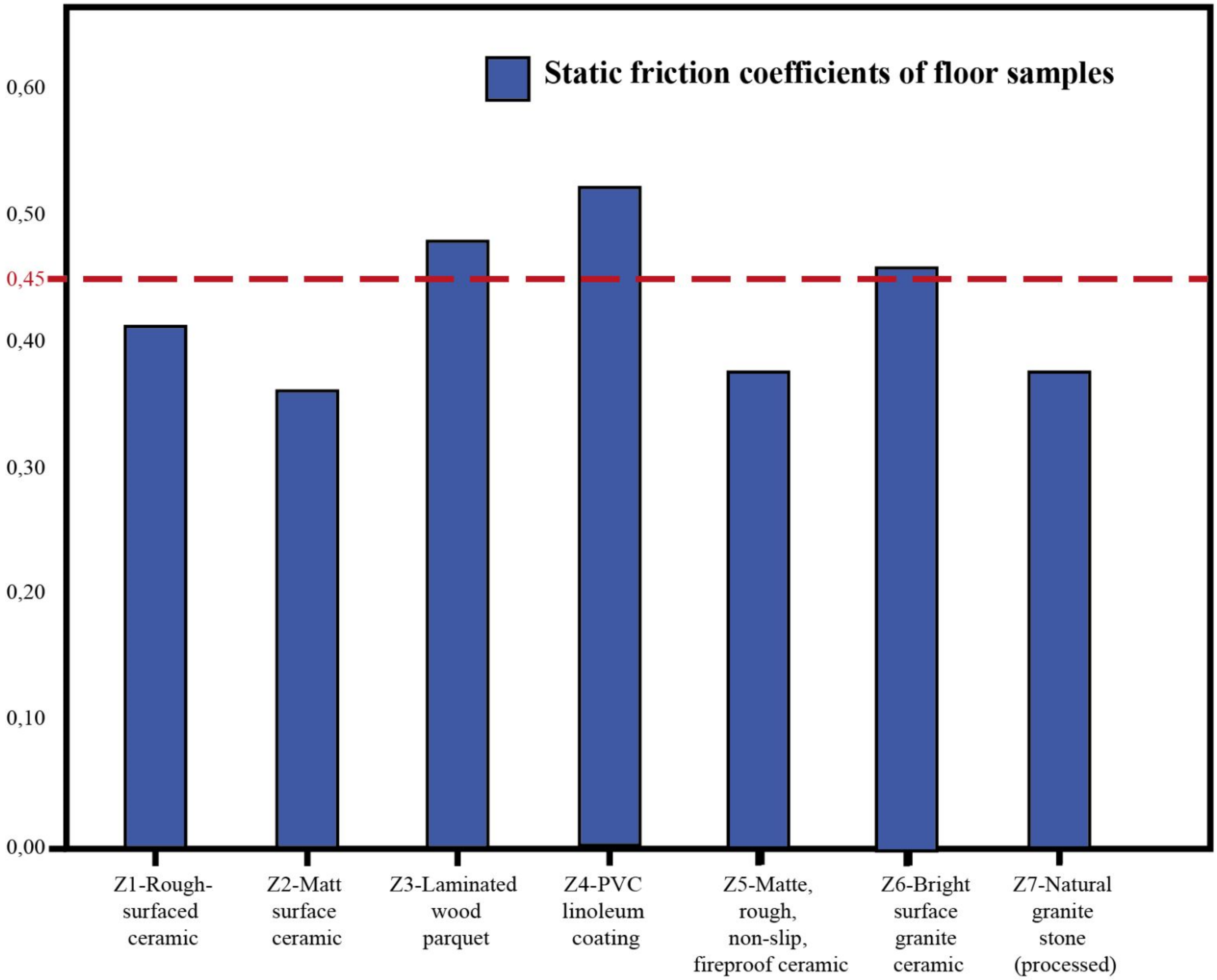

Figure 7. Evaluation of the static friction coefficients of the floor samples according to the reference value

(Mai et al., 2016) used a specially designed measuring device for friction coefficient measurements. In a similar study; they determined that a dry floor has higher friction coefficients than a wet floor and the wet floor has higher friction coefficients than the conditions that are contaminated with surface cleaning material. According to the static friction coefficient values, it has been determined that the dry ground has the lowest slip risk (Çoşkun & Sarıışık, 2017).

Finally, it was observed that only the floor covering material, shoe sole and pollutants are not factors in the occurrence of accidents in slip, stumbling, and falls events. In this study, the correlation between the main intended floor covering material, shoe sole, and pollutants were investigated.

5. Conclusion

In this study, we investigated the correlation between the shoe sole samples with various physical and structural features worn by the workers in the floor samples commonly used in working environments, when they are exposed to two different contaminants with dry ground. ANOVA results showed that the floor covering, shoe sole samples, and floor contaminants were significant for each variable of the friction coefficient (μ) ($p < 0.05$). It was determined that the correlation between two factors and three factors between the floor covering, shoe sole samples, and floor surface contaminant conditions significantly affects the friction coefficient (μ). According to DIN 51097 and DIN 51130, the low-slip risk value is set as $0.42 \leq \mu$ and above. The safe slip risk level according to ASTM and UL is between $0.50 \leq \mu < 0.60$ and the highly safe slip risk level is $0,60 \leq \mu$. It is predicted that the selection of flooring materials to be used in working environments is important to prevent injuries, disabilities, and deaths that may occur due to accidents caused by slipping, stumbling, and falling.

Seven floor samples used in the study were evaluated in terms of safety classification and the results ranking from the highest to the lowest were "Granite ceramic with a glossy surface", "PVC linoleum coating", "Laminated wood parquet", "Matte surface ceramic", "Rough surfaced ceramic", "Matte, rough, non-slip, fireproof ceramic, "Natural granite stone (processed)".

When the effect of floor samples on the static friction coefficient is examined, safe ones according to the DIN 51097 standards for all working areas; it has been determined that "PVC linoleum coating" ($\bar{X}$ = 0.52), "Laminated wooden parquet" ($\bar{X}$ = 0.48), "Granite ceramic with a glossy surface" ($\bar{X}$ = 0.46).

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