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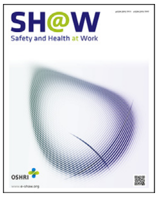

Original Article

Investigation of Floor Surface Finishes for Optimal Slip Resistance Performance

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ABSTRACT

Background: Increasing the slip resistance of floor surfaces would be desirable, but there is a lack of evidence on whether traction properties are linearly correlated with the topographic features of the floor surfaces or what scales of surface roughness are required to effectively control the slipperiness of floors.
Objective: This study expands on earlier findings on the effects of floor surface finishes against slip resistance performance and determines the operative ranges of floor surface roughness for optimal slip resistance controls under different risk levels of walking environments.
Methods: Dynamic friction tests were conducted among three shoes and nine floor specimens under wet and oily environments and compared with a soapy environment.
Results: The test results showed the significant effects of floor surface roughness on slip resistance performance against all the lubricated environments. Compared with the floor-type effect, the shoe-type effect on slip resistance performance was insignificant against the highly polluted environments. The study outcomes also indicated that the oily environment required rougher surface finishes than the wet and soapy ones in their lower boundary ranges of floor surface roughness.
Conclusion: The results of this study with previous findings confirm that floor surface finishes require different levels of surface coarseness for different types of environmental conditions to effectively manage slippery walking environments. Collected data on operative ranges of floor surface roughness seem to be a valuable tool to develop practical design information and standards for floor surface finishes to efficiently prevent pedestrian fall incidents.

1. Introduction

Pedestrian footpaths and walkways should be built to provide safe and comfortable ambulation. They also should deliver optimal slip resistance qualities against any slippery environments throughout their lifetimes. Although supporting and controlling slip resistance properties of the floor surfaces would be desirable as a general rule, a specific problem arises in real-world walking situations. That is, with repeated walking, the surface finishes of floors and walkways seem to experience considerable changes owing to aging of flooring materials, wear and tear, soiling, and maintenance [1,2]. As a result, the slip resistance functions of floors and floor coverings deteriorate over time.

Surface finishes of the floors and shoes have been measured and analyzed by roughness parameters to identify correlations between the surface coarseness and slip resistance properties [2–16]. Those studies report that surface roughness of the shoes and floors significantly affect slip resistance performance. Surface roughness offers drainage spaces to avoid squeeze film formations under polluted environments. For example, when the shoe heel/sole surface has a distinct macroroughness (tread patterns), the voids between asperities act as reservoirs for the liquid under lubricated conditions, and the pressure distribution at each asperity summit promotes a local drainage effects and increases direct contacts with the floor surface [13,15,16]. Therefore, macroroughness or tread patterns are commonly designed into the shoe surfaces but become ineffective quickly after being worn [3,4,15–17]. However, the surface roughness of the floor seems to provide better effects on slip resistance performance than the shoe one because floor surface finishes may offer sharper, taller, and tougher texture in their surface features [3,5,6].

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Regarding the effect of surface roughness, it also should be considered that a very high level of traction or slip resistance may impede safe and comfortable ambulation although intensifying slip resistance properties of the floor surface would be ideal as a general rule [18]. Moreover, maintaining and/or increasing the surface roughness of the floors and floor coverings would require high sustaining and processing costs.

Even though numerous experimental and analytical studies on the prevention of slip and fall incidents are found in the literature, no theoretical concept and/or model is developed to predict the effect of floor surface finishes on slip resistance performance. In particular, it is difficult to find any definitive study and/or design information for operational ranges of floor surface finishes required for optimal slip resistance performance. There are also no internationally accepted guidelines and design data on operational levels of floor surface coarseness for the effective control of slip resistance functioning. Therefore, it is necessary to develop a method that can provide practical design information for the floor surface finishes against a range of walking environments.

This study extends earlier findings on the effect of floor surface features and identifies operative ranges of floor surface roughness for the best slip resistance performance under different slippery environments. The main approach followed the theory concept and model on operational ranges with lower and upper boundaries for the floor surface roughness [13]. Dynamic friction tests were conducted under two different risk levels of unsafe walking environments such as mildly slippery condition (tap water-covered wet) and highly slippery one (machine oil-covered oily) and compared with the moderately high slippery one (soapsuds-covered soapy environment). Based on the test results, operative ranges of floor surface roughness were estimated by polynomial regression models for optimal slip resistance performance under the different environmental conditions.

The current study with the previous outcomes confirms that floor surface finishes require different levels of surface roughness for different types of environmental conditions to effectively control slippery walking situations. It is expected that collected information on operative ranges of floor surface roughness under diverse walking environments can be used as a reference in improving floor surface finishes and accordingly a valuable source to develop practical design information and guidelines for floor surfaces required to prevent pedestrian slip and fall incidents.

2. Materials and methods

To compare findings from the previous study on slip resistance measurements under the soapsuds-covered soapy environment [13,19], the current study followed the same test conditions, methods, and parameters.

2.1. Test conditions

2.1.1. Floor and shoe specimens

For floor specimens, nine new flooring materials were used for dynamic friction tests. Table 1 shows a summary of the floor specimens.

For shoe specimens, three new shoes were used for dynamic friction tests. They were named S1 (Nitrile Rubber: NR 1), S2 (Nitrile Rubber: NR 2), and S3 (Polyvinyl Chloride (PVC)).

The floor and shoe specimens were thoroughly cleaned with demineralized water to remove any dirt and dust, and dried and kept in plastic containers during the tests.

Table 1

Summary of the floor specimens with brief descriptions and surface roughness parameters—R_a, R_t, and R_{tm}

Floor surface no.	Floor surface name	Surface roughness parameter (μm)		
		R_a	R_t	R_{tm}
1	Terrazzo	0.96	8.23	4.85
2	Smooth vinyl tile	1.55	13.61	10.26
3	Smooth metal plate	2.36	13.38	11.76
4	Smooth ceramic tile	3.43	27.50	17.29
5	Smooth concrete slab	6.59	54.00	35.80
6	Moderate rough ceramic tile	14.54	85.51	61.75
7	Moderate rough concrete slab	32.97	337.00	224.33
8	Rough concrete slab	44.11	226.75	159.25
9	Rough ceramic tile	70.94	396.80	141.00

R_a, center line average; R_t, maximum peak-to-valley height; R_{tm}, maximum mean peak-to-valley height.

2.1.2. Environmental conditions

Two lubricated walking environments—(1) tap water-covered water wet and (2) machine oil-covered oily conditions—were generated to simulate different risk levels of slippery conditions. A commercial-type machine oil (Shell Talpa 20, kinematic viscosity: 343 cSt at 16°C) was applied to create oily environments. A fixed amount (approximately 15 mL) of tap water and machine oil was separately sprayed over each floor specimen (surface size: 110 mm × 170 mm) for the wet and oily conditions prior to conducting the tests.

Dynamic friction tests were taken initially under the wet condition and then under the oily one. The surfaces of floor specimens were fully cleaned and dried after the tests under the wet environment and further tested under the oily one.

2.2. Instrumentation

2.2.1. Measurements of slip resistance performance

A pendulum-type hydraulic dynamic friction tester was used to quantify slip resistance performance [13,19]. This tester was designed to simulate moving and loading of a foot during heel strike and initial slip, and to determine quantitatively slip requirements as a dynamic friction coefficient (DFC). During the tests, a normal force was kept around 350N, and a sliding speed was controlled at 40 cm/s based on gait studies [13,19–21]. A heel contact angle of 9° was selected based on the result of previous biomechanical studies [13,21]. Each floor–shoe–environment combination was tested 10 times, and its average was adopted as a resultant DFC.

2.2.2. Measurements of floor surface roughness

There are a number of roughness parameters to describe the surface texture and topographic features, but peak height-related roughness parameters such as R_t and R_{tm} were chosen because they were related with maximum peak-to-valley heights that were directly connected to the theory hypothesis and model from the previous study [13,19]. Three roughness parameters, R_a, R_t, and R_{tm}, were assessed to compare with the result of slip resistance measurements under the soapy environment [13,19]. Details on the three roughness parameters are found in the literature [2,22].

The surface roughness parameters of floor specimens were measured by a Talysurf 5 profilometer (Taylor-Hobson, Leicester, UK) that had a conical stylus with a spherical tip of 12-μm radius. A Gaussian filter that was set to a cutoff length of 0.8 mm over a single traverse distance of 17.5 mm was used to remove waviness components of the floor surfaces. Surface profiles of the floor specimens were measured five times at three different locations. Averages of the individual roughness measurements were used for the surface analysis of each floor specimen. Table 1 summarizes the measurement results of roughness parameters for the floor samples.

2.3. *Statistical design and analysis*

Three-way analysis of variance (ANOVA) was carried out to assess the significant effects of floor, shoe, and environment variables and their interactions on the DFCs. A polynomial regression model was used to estimate the interactions between the floor surface roughness parameters and the DFCs. Independent variables for the ANOVA tests included the following elements:

(1) Floor type ("Floor"), with nine different coarseness defined by three surface roughness scales (measured by R_a, R_t, and R_{tm} roughness parameters)
(2) Shoe type ("Shoe"), classified by sole/heel materials including two nitrile rubber (S1 and S2) and one polyvinyl chloride (S3) heels/soles
(3) Walking environment ("Environment"), with two different risk levels of slippery conditions: mildly slippery condition (tap water-covered water wet) and highly slippery one (machine oil-covered oily).

A DFC was adopted as a dependent variable. The DFC value of 0.4 was used as an acceptable safety criterion to determine the lower boundary of operational ranges for floor surface roughness [13,19,23].

Prevalence odds ratios with a 95% confidence interval were calculated as a measurement of association. A *p*-value less than 0.05 was considered statistically significant. Statistical analyses were performed using the Statistical Analysis System (SAS) software, SAS version 9.3 (SAS Institute Inc., Cary, NC, USA).

3. Results

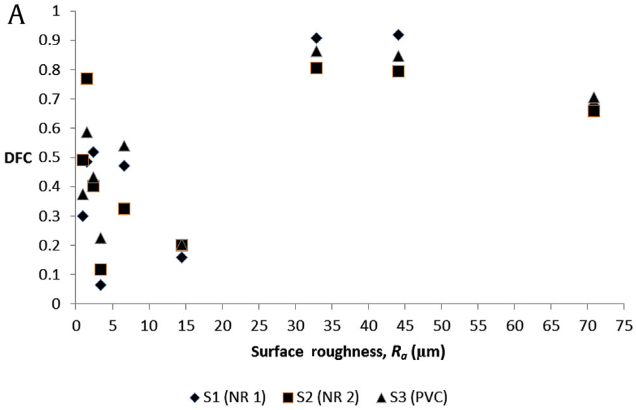
3.1. *Slip resistance performance*

Fig. 1 shows the results of dynamic friction tests among the nine floor and three shoe specimens under the three different risk levels of slippery environments including the outcomes from the soapy condition. The DFCs were arranged by the order of floor surface roughness parameter, R_a. This arrangement was intended to analyze the broad relationship between the surface roughness of each floor specimen and DFC results, and observe the general effect of surface roughness on slip resistance properties.

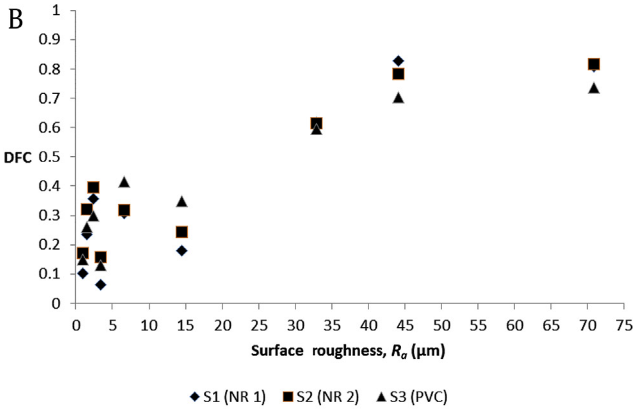
The DFCs mostly increased with the surface roughness of floor specimens. This trend was clearly found under the soapy and oily environments. However, a linear relationship between the floor surface roughness and DFCs was not found in the case of wet surfaces. Some smooth floors (<10 µm in R_a roughness parameter) such as the smooth vinyl tile (No. 2: 1.55 µm in R_a), smooth metal plate (No. 3: 2.36 µm in R_a), and smooth concrete slab (No. 5: 6.59 µm in R_a) showed good slip resistance performance (DFC $>$ 0.4) against the shoes (except S2) under the wet environment.

3.2. *Interactions between floor types and environments*

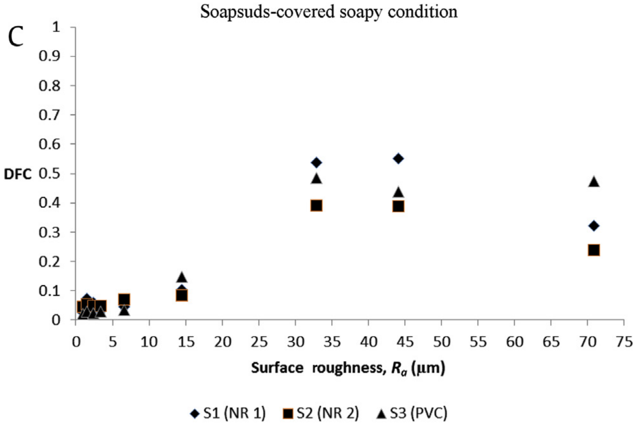
The three-way (Floor × Shoe × Environment) ANOVA results in Table 2 demonstrate strong interactions between the Floor (surface roughness) and Environment variables against the DFCs. The DFCs drastically reduced under the contaminated environments but increased significantly by the floor types with higher surface roughness. However, the effect of floor types was more significant under the soapy and oily environments than the wet one.



Tap water-covered wet condition



Soapsuds-covered soapy condition



Machine oil-covered oily condition

Fig. 1. Results of dynamic friction tests among the nine floor surfaces and three shoes against the surface roughness parameter, R_a under three different environments. (A) Tap water-covered wet condition. (B) Soapsuds-covered soapy condition. (C) Machine oil-covered oily condition. DFC, dynamic friction coefficient; NR 1, Nitrile Rubber 1; NR 2, Nitrile Rubber 2; PVC, polyvinyl chloride.

Table 3 summarizes additional statistical information on the regression analysis between the DFCs and three roughness parameters—R_a, R_t, and R_{tm}—under the three environmental conditions. As shown in Table 3, there were fairly strong correlations between the surface roughness parameters of floor specimens and DFC results against the three contaminated environments. The overall relationships were remarkably significant ($<$0.0001) under the soapy and oily circumstances.

3.3. *Interactions between shoe types and environments*

The three-way ANOVA results in Table 2 demonstrated that there were no interactions between the shoe type (Shoe) and

Table 2
Summary of three-way analysis of variance results among the shoes, floors, and environments of wet, soapy, and oily conditions

Effect on DFC	*df*	Sum of squares	Mean square	*F*	*Pr > F*
Intercept	1	10.80729	10.80729	3727.37	<0.0001
Floor type*	8	3.69161	0.46145	159.15	<0.0001
Environmental condition	2	1.58079	0.79039	272.6	<0.0001
Shoe type	2	0.00298	0.00149	0.51	0.6028
Floor type × Environmental condition	16	0.37556	0.02347	8.1	<0.0001
Floor type × Shoe type	16	0.11600	0.00725	2.5	0.0133
Environmental condition × Shoe type	4	0.01615	0.00404	1.39	0.2588
Error	32	0.09278	0.00290		

* Floor type as a categorical variable.
df, degrees of freedom; DFC, dynamic friction coefficient.

walking environment (Environment) variables against the DFCs. Some of the shoe types performed better than others, but this effect was evident only in the wet environment. For example, S1 performed better than S2 and S3 against certain types of floor surfaces, whereas S3 was better than S2 generally. Under the soapy and oily environments, however, all three shoes were not at all effective in supporting slip resistance performance as compared to the floor-type effect.

3.4. Operational ranges of floor surface roughness

Fig. 2 shows the results of polynomial regression to estimate the interactions between the three roughness parameters, R_a, R_t, and R_{tm}, of floor specimens and the DFCs under the three polluted environments. The cubic functions of regression equations demonstrate possible operational relationships between the floor surface roughness parameters and DFCs against each environmental condition. Using the regression model and the safety requirement for DFC > 0.4, it was projected that the lower boundary ranges for floor surface roughness were:

- $R_a \cong 35$ μm, $R_t \cong 210$ μm, and $R_{tm} \cong 130$ μm for the oily environment.
- $R_a \cong 17$ μm, $R_t \cong 120$ μm, and $R_{tm} \cong 75$ μm for the soapy environment

The regression curves in Fig. 2 also present that with increments of floor surface roughness the DFCs reach top no-growth or peak levels (Zone 3) after certain scales of floor surface roughness under the three lubricated environments. From the regression model, it was also projected that the upper boundary ranges for floor surface roughness were:

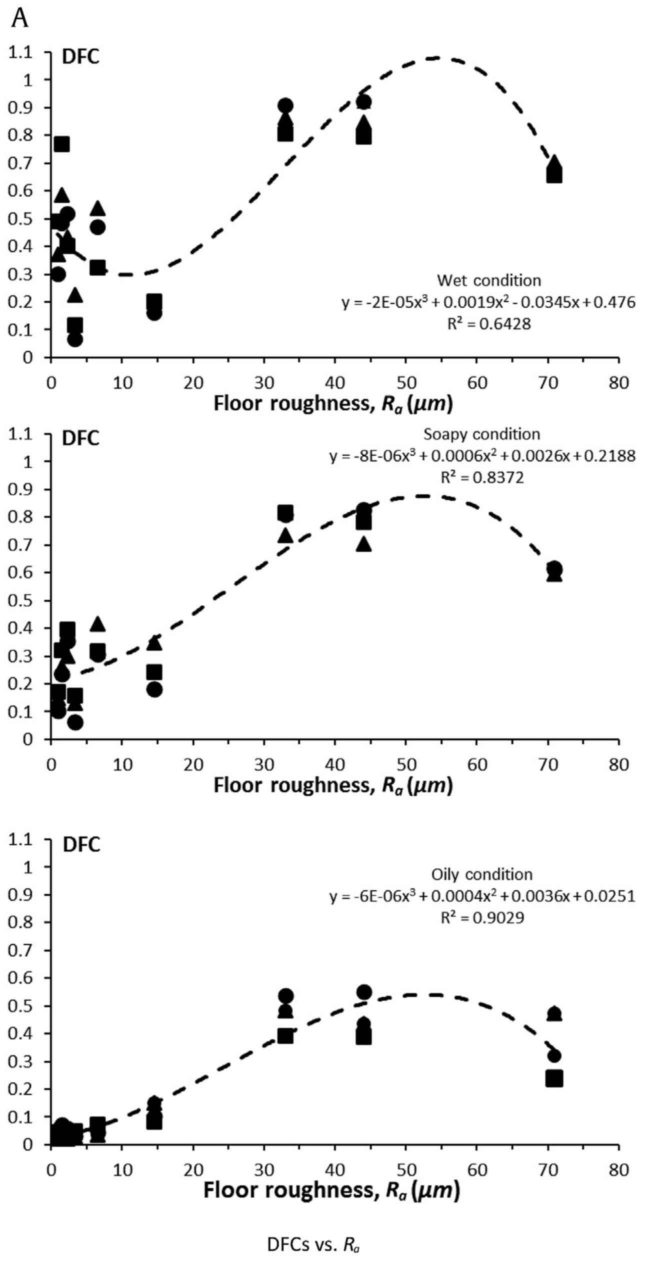


Fig. 2. Scattered plots and polynomial regression lines of the DFCs and the three floor surface roughness parameters—R_a, R_t, and R_{tm}—for the water-covered wet, soapsuds-covered soapy, and machine oil-covered oily conditions, respectively. (A) DFCs versus R_a. (B) DFCs versus R_t. (C) DFCs versus R_{tm}. DFCs, dynamic friction coefficients.

- $R_a \cong 52$ μm, $R_t \cong 300$ μm, and $R_{tm} \cong 180$ μm for the oily environment.
- $R_a \cong 52$ μm, $R_t \cong 300$ μm, and $R_{tm} \cong 180$ μm for the soapy environment.
- $R_a \cong 52$ μm, $R_t \cong 300$ μm, and $R_{tm} \cong 180$ μm for the wet environment.

Table 4 summarizes the result of detailed statistical information for the regression functional analysis on the DFCs, which are predicted by the three cubic functional parameters under the three contaminated environments. They clearly demonstrate the importance of three roughness parameters on the DFCs.

Table 3
Additional statistical analysis result: regression analysis between DFCs and three roughness parameters (R_a, R_t, and R_{tm}) was performed under wet, soapy, and oily environments

Environment	Model	*df*	R^2	*F*	*Pr > F*
Wet	R_a	3	0.6428	13.80	<0.0001
	R_t	3	0.6936	17.35	<0.0001
	R_{tm}	3	0.6995	17.84	<0.0001
Soapy	R_a	3	0.8372	39.43	<0.0001
	R_t	3	0.8738	53.07	<0.0001
	R_{tm}	3	0.8665	49.77	<0.0001
Oily	R_a	3	0.9029	71.31	<0.0001
	R_t	3	0.9309	103.25	<0.0001
	R_{tm}	3	0.9295	101.07	<0.0001

df, degrees of freedom; R_a, center line average; R_t, maximum peak-to-valley height; R_{tm}, maximum mean peak-to-valley height.

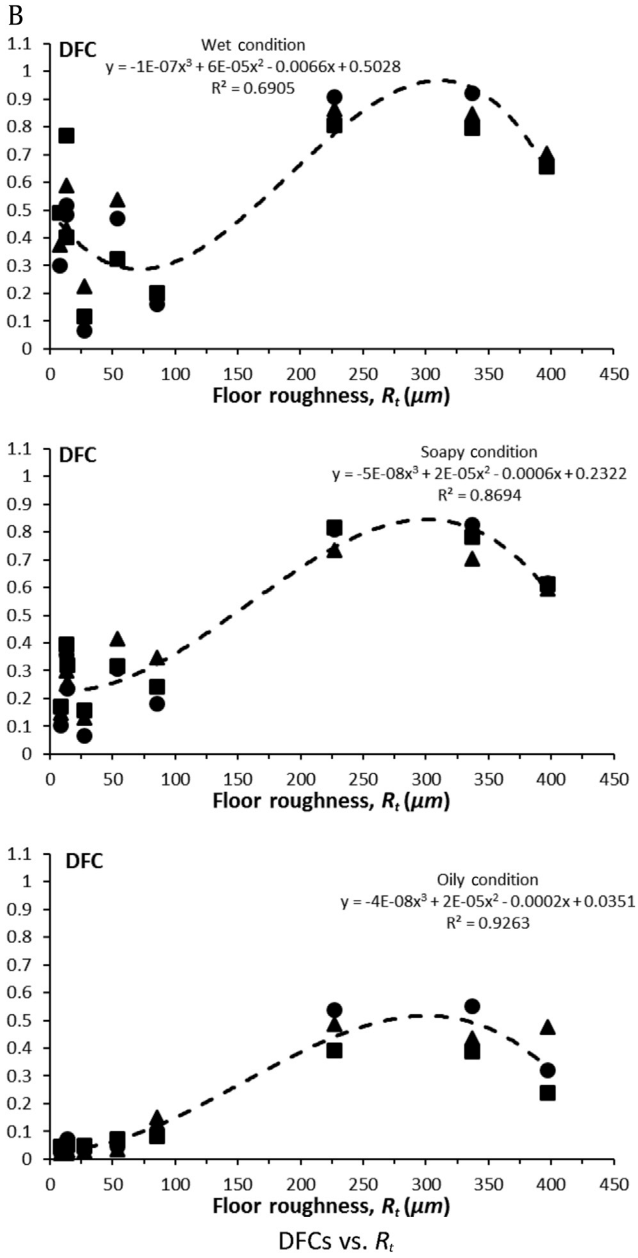


Fig. 2. (*continued*).

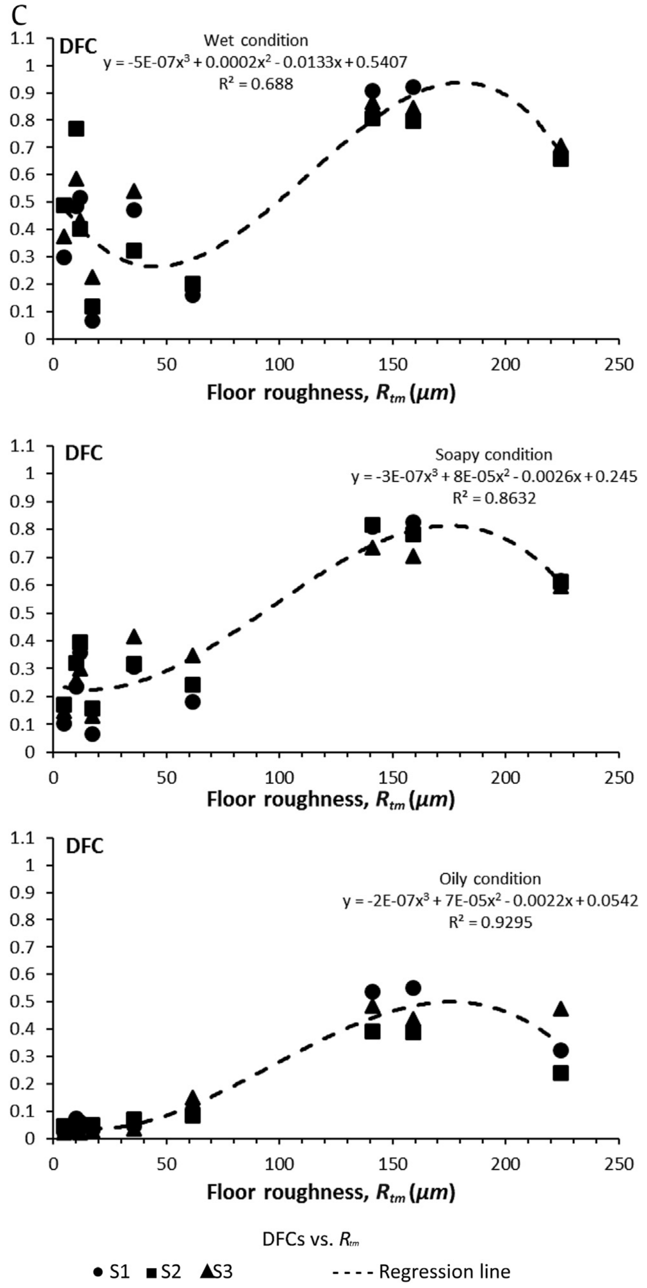


Fig. 2. (*continued*).

4. Discussion

4.1. Interactions between floor types and environments

There were significant correlations between the floor surface roughness and DFCs under the three polluted environments. When the floor surfaces were contaminated, the role of floor surface finishes was very significant to increase slip resistance performance. This effect was notable under the highly risky environments such as soapy and oily conditions. As shown in Fig. 2, acceptable slip resistance performance under such excessive slippery conditions was validated only by the three rough floors with surface roughness >30 μm in R_a roughness parameter: the moderate rough concrete slab (No. 7: R_a = 32.97 μm), rough concrete slab (No. 8: R_a = 44.11 μm), and rough ceramic tile (No. 9: R_a = 70.94 μm). As summarized in Table 1, R_t and R_{tm} parameters of these three-floor specimens also showed correspondingly high scales.

As the surface roughness of floor specimens was raised from 14.54 μm to 32.97 μm in R_a roughness parameter, this increment was even sufficient enough to improve slip resistance performance from a dangerously low level to marginally safe one in the DFCs (> 0.4) under the machine oil-covered highly slippery condition. However, further increases in floor surface roughness did not provide additional benefits to the slip resistance performance under all three environments. This result was consistent with other studies reporting functional relationships between the floor surface roughness and DFCs against contaminated conditions [13,19,24–27].

It was also found that there was a lack of correlation between the floor types and DFCs under the wet environment. This finding indicates the involvement of multiple mechanisms of slip

Table 4

Detailed statistical analysis result: DFCs were predicted by cubic functions of three roughness parameters (R_a, R_t, and R_{tm}) under wet, soapy, and oily environments

Surface condition	Roughness parameter	Variable	*df*	Par. estimate	Standard error	*t*	*Pr* > |*t*|
Wet	R_a	Intercept	1	0.2188	0.0413	7.45	<0.0001*
		Linear	1	0.0026	0.0095	−2.34	0.0282*
		Quadratic	1	0.0006	0.0004	3.38	0.0026*
		Cubic	1	-8.1×10^{-6}	3.31×10^{-6}	−3.7	0.0012*
	R_t	Intercept	1	0.2358	0.0397	7.80	<0.0001*
		Linear	1	−0.0008	0.0014	−2.92	0.0078*
		Quadratic	1	2.54×10^{-5}	8.73×10^{-6}	4.01	0.0006*
		Cubic	1	-5.32×10^{-8}	1.44×10^{-8}	−4.23	0.0003*
	R_{tm}	Intercept	1	0.2381	0.0445	7.65	<0.0001*
		Linear	1	−0.0014	0.0026	−3.03	0.0060*
		Quadratic	1	5.32×10^{-5}	2.72×10^{-5}	3.58	0.0016*
		Cubic	1	-1.60×10^{-7}	7.66×10^{-8}	−3.42	0.0024*
Soapy	R_a	Intercept	1	0.0251	0.0242	5.30	<0.0001*
		Linear	1	0.0036	0.0056	0.28	0.7838
		Quadratic	1	0.0004	0.0002	1.72	0.0990
		Cubic	1	-5.8×10^{-6}	1.94×10^{-6}	−2.45	0.0225*
	R_t	Intercept	1	0.0379	0.0223	5.94	<0.0001*
		Linear	1	−0.0004	0.0008	−0.58	0.5684
		Quadratic	1	1.81×10^{-5}	4.91×10^{-6}	2.91	0.0079*
		Cubic	1	-3.85×10^{-8}	8.09×10^{-9}	−3.69	0.0012*
	R_{tm}	Intercept	1	0.0493	0.0246	5.35	<0.0001*
		Linear	1	−0.0014	0.0014	−0.54	0.5940
		Quadratic	1	4.61×10^{-5}	1.5×10^{-6}	1.95	0.0630
		Cubic	1	-1.40×10^{-7}	4.23×10^{-8}	−2.09	0.0479*
Oily	R_a	Intercept	1	0.2188	0.0413	1.04	0.3109
		Linear	1	0.0026	0.0095	0.65	0.5240
		Quadratic	1	0.0006	0.0004	2.02	0.0552
		Cubic	1	-8.1×10^{-6}	3.31×10^{-6}	−2.99	0.0066*
	R_t	Intercept	1	0.2358	0.0397	1.70	0.1023
		Linear	1	−0.0008	0.0014	−0.45	0.6582
		Quadratic	1	2.54×10^{-5}	8.73×10^{-6}	3.68	0.0012*
		Cubic	1	-5.32×10^{-8}	1.44×10^{-8}	−4.76	<0.0001*
	R_{tm}	Intercept	1	0.2381	0.0445	2.01	0.0564
		Linear	1	−0.0014	0.0026	−0.99	0.3346
		Quadratic	1	5.32×10^{-5}	2.72×10^{-5}	3.07	0.0054*
		Cubic	1	-1.60×10^{-7}	7.66×10^{-8}	−3.31	0.0030*

* Indicates significant $p < 0.05$.

df, degrees of freedom; R_a, center line average; R_t, maximum peak-to-valley height; R_{tm}, maximum mean peak-to-valley height.

resistance properties and possible effects of other tribo-physical characteristics such as hydrodynamic and boundary lubrication effects, wear developments of the floor and shoe surfaces, and their interactive effects against the water-wet condition during the dynamic friction tests. These aspects require further studies to investigate their complex tribo-physical behaviors and impacts on slip resistance performance.

4.2. *Interactions between shoe types and environments*

The interactions between the shoe types and environmental conditions demonstrated that there were no shoe effects to improve slip resistance performance under the soapy and oily environments (Table 2). This result suggests that introducing rough floor surface seems to be a more effective strategy to increase slip resistance performance under such highly slippery environments.

4.3. *Operational ranges of floor surface roughness*

The test results from cubic functions of each roughness parameter showed nonlinear relationships between the floor surface roughness and DFCs. This finding confirmed that the higher slip resistance performance was not mechanically supported by the rougher floors as assumed in an earlier study [13]. Some smooth floor specimens such as the smooth vinyl tile (No. 2: $R_a = 1.55$ μm), smooth metal plate (No. 3: $R_a = 2.36$ μm), and smooth concrete slab (No. 5: $R_a = 6.59$ μm) showed relatively good slip resistance performance under the wet and soapy conditions. However, their slip resistance properties were dangerously low under most of the soapy and oily environments. Thus, they should not be treated as an exception from the suggested operational roughness ranges of floor surfaces. This aspect of slip resistance properties made it difficult to estimate the lower boundary ranges for floor surface roughness under the wet surface condition.

The test results also identified that increasing the floor surface roughness beyond certain scales did not provide further benefits for slip resistance performance. This means that there seem to be present operational roughness ranges for optimal slip resistance performance. For example, floor surface roughness in the scales of 35–52 μm (R_a roughness parameter) would be an effective range for the oily environment, whereas floor surface roughness in the scales of 17–52 μm (R_a roughness parameter) would be an efficient one for the soapy environment. These outcomes demonstrate that the oily environment requires twice rougher floor surface roughness than the soapy one in their lower boundary roughness scales: 35 μm versus 17 μm in R_a roughness parameter.

However, it is interesting to note that the upper boundaries of floor surface roughness show the same ranges of surface roughness scales: 52 μm in R_a, 300 μm in R_t, and 180 μm in R_{tm} roughness parameters under the three contaminated environments. This finding clearly identifies that sustaining minimum (lower boundary) roughness scales of the floor surface seem to be a critical matter to effectively control slip resistance performance under highly lubricated circumstances.

Table 5 summarizes the operational ranges (lower and upper boundaries) of the floor surface roughness parameters for optimal slip resistance performance against the three lubricated environments. As shown in Table 5, the three roughness parameters provide additional data on the operative roughness ranges with lower and upper boundaries for the floor surfaces. The significant

Table 5
Summary of operational ranges (lower and upper bounds) of floor surface roughness parameters under three lubricated environments

Surface roughness parameters	Optimal operational range (μm) with lower and upper bounds under three environments		
	Wet	Soapy	Oily
R_a	5 (21)–52	17–52	35–52
R_t	25 (135)–300	120–300	210–300
R_{tm}	15 (80)–180	75–180	130–180

R_a, center line average; R_t, maximum peak-to-valley height; R_{tm}, maximum mean peak-to-valley height.

relationships between the current and previous studies verified the theory concept and model on operative roughness ranges for the floor surfaces.

Outcomes on the operational ranges of floor surface roughness signify that we may not always need to choose rougher floors and/or treat floor surfaces to roughening for the prevention of pedestrian fall incidents. Hence, floor surfaces may require different levels of coarseness for different types of environmental conditions to effectively and efficiently manage walkway slipperiness. The inclusive results from this study suggest that the proposed concept on operational roughness ranges for the floor surface finishes may have practical design implications for floors and floor coverings to provide optimal slip resistance functioning.

5. Conclusion

This study aimed to investigate the effects of floor surface finishes on slip resistance properties and identify the operational ranges of floor surface roughness for optimal slip resistance performance under different risk levels of slippery environments. The test results showed significant effects of floor surface roughness on slip resistance performance under the contaminated conditions. However, there was a lack of correlations between the surface roughness and DFCs under the wet environment. This aspect indicated an involvement of complex mechanisms of slip resistance properties and possible effects of other tribo-physical characteristics among the floor surfaces, shoe heels, and water wet environment.

Slip resistance performance was significantly affected by and well correlated with floor surface finishes under the highly slippery environments such as soapy and oily conditions. Polynomial regression models for the floor surface roughness and DFC interactions allowed estimating operational ranges of floor surface roughness for optimal slip resistance performance. Floor surfaces with around 17–52 μm and 35–52 μm in R_a roughness parameter most likely represented the lower and upper boundaries of operational ranges for the best slip resistance controls under the soapy and oily environments, respectively.

Overall results evidently demonstrate that the floor surface finishes require different levels of surface roughness for different types of environmental conditions to effectively control slippery walking environments. This study suggests that the propositioned concept on operational ranges with lower and upper boundaries for the floor surface roughness may have applicable design implications for floors and floor coverings to provide optimal slip resistance implementation.

6. Limitations

This study tested a narrow selection of flooring materials within limited types and ranges of surface roughness. Further research on the slip resistance properties of walkways requires testing a variety of floor and flooring materials with different surface features in order to accurately determine the specific functional ranges of surface roughness. The efficiency of floor surface roughness for evaluating slipperiness also needs to measure with human volunteers to enhance a reliability of fall safety assessment.

The experimental design of this study included three different risk levels of environmental conditions: wet, soapy, and oily situations. This may limit the applicability of the findings only to those types of contaminated circumstances. Other categories of surface pollutants with different composition and viscosity may result in different functional levels of surface roughness.

It also can be considered that different types of friction testers and/or apparatuses to measuring slip resistance or traction properties may produce different results. This likelihood also needs to be explored in future studies with the above-mentioned issues and limitations, which are ongoing.

Conflicts of interest

The contributing author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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