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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

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