

The impact of machine cleaning on the slip resistance of commercial floors coated with floor finish

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Abstract

Preventing slip, trip and fall events in commercial facilities is an important part of operating a safe facility. Flooring surfaces in commercial buildings are often coated with removable floor finish and maintained with a range of floor maintenance procedures and products, often using floor care machines, but their impact on finished floor slip resistance is poorly reported. In this study, vinyl composite floor tiles were coated with four coatings of four different floor finishes and a range of floor maintenance practices were performed for seven days using floor care machines and various floor maintenance products to determine the impact on the coefficient of friction/slip resistance using the James Machine and a modified ASTM D2047 test method. None of the floor maintenance products or procedures substantially changed the slip resistance of the finished floor tiles. There were some statistically significant changes in the coefficient of friction for some product/finish combinations, but in all cases, all tiles passed ASTM D2047's standard for static coefficient of friction. This study suggests that when a machine is cleaning a finished floor, the maintenance products used on the floor have minimal impact on the slip resistance of the floor and are unlikely to make the floor a slip-fall hazard.

1. Introduction

Commercial facilities have an obligation to provide safe walking surfaces for their employees and the general public who use the facilities. Despite the obvious importance of providing safe walking surfaces, many facilities struggle to avoid slip, trip and fall (ST&F) accidents, and ST&F accidents continue to be an important public safety issue. In the USA alone, falls by employees were reported to be 15.3 % of all workplace accidents, with an estimated impact of \$8.98 billion in direct costs associated with the accidents [1]. These data are likely only a portion of the overall impact of ST&F events, as ST&F events for the general public are not centrally reported in the USA and other countries. Falls in the USA are reported to be the leading cause of preventable death for people aged 75 to 84 [2]. The National Safety Council [2] further

reports that falls are the top cause of non-fatal injuries for people in the USA, with an estimated 8.8 million people treated in emergency departments and 47,026 deaths as a result of a fall each year.

The ST&F events are complex to analyse because of the wide range of factors and incident-specific conditions that contribute to an ST&F event [3-6]. Multiple authors have investigated various aspects or factors contributing to an ST&F event in an attempt to separate various factors of the event for analysis [3-6]. This research has led to a better understanding of how a person's physical state, postural state and biomechanics of movement [4,5,7-10], a person's mental state [7,10-12] and the environmental conditions of the facility, including the condition of the floor [5-7,12-14], may play a role in an ST&F event. Because of this complexity, it is difficult to apportion the relative contribution of the various factors [5,11,15]. Of the contributing factors, those related to the physical commercial facility, such as the condition of the floor, choice of flooring material,

obstacles on walkways and quality of overhead lighting, are arguably most within the facility's control and when managed properly, are believed to reduce a significant portion of the risk of ST&F events [2,6,13]. Floor safety regulations exist but are often ambiguous, requiring facility floors be slip resistant, but lacking clear definitions of what constitutes a slip-resistant walking surface or how appropriate levels of slip resistance are to be measured [16,17], making it challenging for a commercial facility to have confidence in their floor's safety. Portable tribometers are often used to provide a measure of floor safety, but their predictive power in determining ST&F risk is controversial for many reasons including whether their use accurately simulates all the important factors that impact ST&F risk [3,13,15,17,18]. As an example, portable tribometers cannot account for differences in the postural control of a person, step-to-step variability in gait, differences in leg speed during the swing phase, differences in angle of contact with the floor and shoe wear and tear that may have occurred to a person at the time of an accident. A full discussion of the best scientific method for measuring the slip resistance of a floor and quantifying the associated ST&F risk is beyond the scope of this study, but in many countries, regulatory authorities provide at least limited guidance on how to determine whether a floor should be considered slip-resistant [19].

For example, in the USA, the Occupational Safety and Health Administration (OSHA) requires that walking and working surfaces be slip-resistant and that a reasonable measure of a floor's slip resistance is a static coefficient of friction (SCOF) greater than 0.5 [19]. OSHA further states that while studies have shown that a floor with an SCOF greater than 0.5 is generally considered slip-resistant, this is not an absolute value, and in some situations, a floor may need a higher SCOF to be slip-resistant [19]. This guidance may conflict with the results of published studies for a range of reasons, including testing method, a person's risk tolerance and the range of ST&F factors considered [16,20]. An alternative to measuring the SCOF of a floor is to measure the dynamic coefficient of friction (DCOF), which attempts to measure the slip risk of an object in motion with the floor, simulating a foot during a leg swing [21,22]. Multiple authors have argued that because the coefficient of friction found using a portable tribometer is not a unique number, but is a result of the test method, conditions and tribometer

used, it is likely that the minimum coefficient of friction needed to prevent a slip is test method dependent, making it challenging to measure a floor's DCOF and then accurately predict the ST&F risk [7,15,21-23]. Despite these limitations, many countries use DCOF measures as an alternative to SCOF in floor-safety regulations.

For facilities using decorative removal floor coatings (i.e. removable floor finishes), there is a widely accepted ASTM D2047 standard that can be used to measure the slip resistance of the finished floor, helping to ensure a slip-resistant walking surface [24]. Using floor finish on the flooring of a commercial facility can help reduce ST&F risk in several ways, including providing a walking surface with consistent slip resistance, reflecting light to improve visibility and making floors easier to clean, allowing rapid removal of inevitable contamination. Finished floors require routine maintenance to remove soil and contamination from the floor, repair cracks and scratches in the floor finish and maintain the gloss of the floor finish. Floor maintenance practices help ensure the floor finish remains as slip-resistant as when the finish was first applied to the floor and are often performed using floor machines, such as scrubber dryers (autoscrubbers), low-speed swing machines or ultra-high-speed burnishers to apply floor maintenance products to the finished floor or as part of the maintenance process.

Unlike floor finishes, the range of maintenance practices and cleaning products commonly used on finished floors is generally not tested to ensure they do not negatively impact the slip resistance of the floor finish while in use. Floor maintenance, whether using a neutral cleaner, a disinfectant, applying a spray buff or using a cleaner-maintainer, leaves small amounts of the maintenance products on the floor finish. While there is a standard slip resistance testing procedure for floor finish, namely using ASTM D2047, which tests hand-coated flooring tiles in the laboratory on the James Machine [24], there is no similar widely accepted standard testing procedure to test the impact of floor maintenance products on the slip resistance of the finished floor.

There is little evidence in the literature on the impact of performing routine floor maintenance on the slip resistance of floor finishes. Testing of finish-coated floor tiles using ASTM D2047 is done in the laboratory. Testing finished floor tiles under real-world conditions is a challenge because the floor tiles cannot be readily removed for

laboratory testing without damaging them. While routine floor maintenance is necessary to remove contamination and ensure the floor finish works as expected, it is unclear whether this routine floor maintenance has an impact on the floor finish that affects the slip resistance. When a maintenance product is used on a floor, there is likely to be residual left on the floor. Interactions between the floor finish and residual from the floor maintenance product have the potential to impact the slip resistance of the floor. It is expected that the residual does not cause a drop in the SCOF of the floor that could indicate a decrease in the slip resistance of the floor after the maintenance procedure has been performed. This study is novel in investigating this concern. To test the impact of routine floor maintenance procedures on finished floors, a portable tribometer is commonly used, but the correlation between testing with a portable tribometer and the James Machine using ASTM D2047 has not been demonstrated and remains controversial [3,15,18,21,23].

The aim of this study was to investigate the impact of using various floor maintenance products on the slip resistance of a range of floor finishes on a floor with removable tiles, where a standard floor machine was used to apply the products as part of the floor maintenance procedure.

2. Materials and methods

2.1 Floor installation

A magnetic floor of approximately 3.7×7.6 m (27.9 m²), i.e. 12×25 ft (300 ft²) was installed over an existing concrete floor using Armstrong Premium Excelon M601C black vinyl composite tiles (Fig. 1). Steel strips were attached to the concrete base with adhesive and magnetic backings were applied to the vinyl composite tiles, allowing for easy tile removal to facilitate testing in the laboratory on the James Machine, overcoming the limitation of being able to remove floor tiles for testing in the laboratory.

2.2 Floor finishes

A selection of four floor finishes from the leading floor finish manufacturer in the USA was included in the study, as shown in Table 1. All finishes are commercially available in the USA market and are sold for use in a wide range of commercial facilities. The selected floor finishes are formulated with different long-chain acrylic

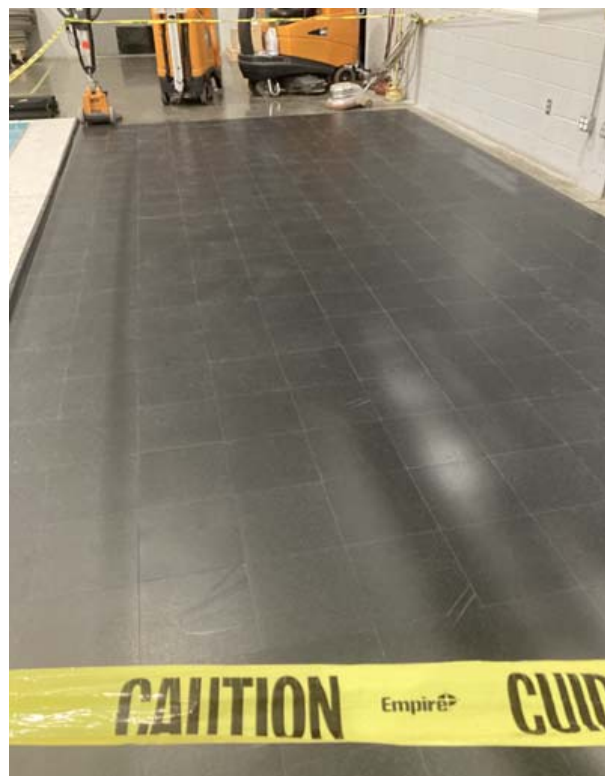


Figure 1. Photo of the installed magnetic floor with removable tiles; reprinted from Teska et al. [25], licensed under CC BY-NC 4.0

and styrene polymers, which provide different performance characteristics. The selection of the polymer backbone impacts the choice and amounts of the other ingredients, as different resins, waxes, plasticisers and surfactants can impact the overall performance, including the slip resistance, of the formulated floor finish. In this study, Finish A is formulated with polymers designed to provide a high level of gloss, which requires daily high-speed maintenance procedures to maintain the gloss level. This finish is commonly used in big-box retail stores in the USA by retailers wanting a "wet look" high-gloss floor. Finish B was formulated with polymers designed to provide a high gloss level (but with less gloss than Finish A) and a durable finish requiring less than daily maintenance, which can be maintained with low (approximately 175 rpm) or high-speed (at least 2000 rpm) maintenance procedures. Finish C is a multi-substrate finish designed to be used on resilient and non-resilient floors with a medium level of gloss and the ability to be maintained with high- and low-speed maintenance procedures. Finish C is commonly used on terrazzo, granite and other non-resilient floor substrates, but can also be used on resilient floor substrates. Finish D is formulated as a high solids, medium-gloss finish intended for high-speed maintenance procedures.

Table 1. Floor finishes used in the study

Product	Finish description from the company website
Finish A	Ultra-high-speed floor finish with maximum wet-look gloss
Finish B	High-durability high-gloss finish with soil resistance
Finish C	Multi-maintenance floor finish
Finish D	High solids, low odour finish

2.3 Floor maintenance procedures and maintenance products

There is a wide range of floor maintenance procedures used on finished floors in commercial facilities.

Daily cleaning is typically performed using a neutral cleaner, disinfectant or cleaner-maintainer. The daily cleaning product is applied to the floor and used cleaning solution is removed from the floor using a scrubber dryer floor machine. This procedure is done both to finished and unfinished commercial floors. For finished floors, the primary purpose of this procedure is the removal of contamination embedded in the floor finish.

Spray buffing is generally performed on a weekly schedule as an interim procedure to help restore the gloss to the floor finish without applying more coatings of finish. The finished floor

is cleaned daily with a neutral cleaner using a scrubber dryer floor machine and once a week a spray buff is applied after the daily cleaning. Using a trigger spray bottle, the worker applies the Spray buff on the floor ahead of using a low-speed (i.e. 175 rpm) swing machine and then buffs the floor, working the Spray buff into the finish, restoring gloss to the finish. This procedure is only done on finished commercial floors that are coated with floor finishes that respond to spray buffing, and only after first cleaning the floor.

Cleaner-maintainers are used in place of daily cleaners and are designed to fill cracks and scratches in the floor finish while cleaning it. Some cleaner maintainers are designed to work without burnishing and others are designed to be burnished after application to restore floor finish gloss. Commonly, the facility cleans the finished floor daily using the cleaner-maintainer at one dilution and then once per week follows the cleaning at a stronger dilution, followed by burnishing of the finish and then dust mopping to remove any dust generated by the burnishing. This procedure is only done on finished floors that are coated with floor finishes that respond to high-speed (i.e. at least 2500 rpm) burnishing.

Table 2 identifies the floor maintenance procedure associated with the floor maintenance product at the shown use dilution. As an example, product NC-A is a premium neutral cleaner used at a dilution of 1 ml product to 512 ml water. At this

Table 2. Floor maintenance products, typical maintenance procedures and finishes they were used on

Code	Product description	Use dilution	Tested maintenance procedure			Finishes used on			
			daily cleaning	spray buffing	cleaner-maintainer	Finish A	Finish B	Finish C	Finish D
NC-A	Premium neutral cleaner	1:512	yes			yes	yes	yes	yes
NC-B	Economy neutral cleaner	1:750	yes			yes	yes	yes	yes
Dis-A	Economy quaternary disinfectant	1:256	yes			yes	yes	yes	yes
Dis-B	Premium quaternary disinfectant	1:256	yes			yes	yes	yes	yes
CM-A	Cleaner-maintainer	1:512	yes			yes	yes	yes	yes
SB-A	Spray buff	RTU		yes			yes	yes	
CM-B	Cleaner-maintainer	1:256			yes	yes	yes	yes	yes
CM-C	Cleaner-maintainer	1:64			yes	yes	yes	yes	yes

Code – alphanumeric identifier used during the study; use dilution – indicates the ml of water to be combined with 1 ml of product; RTU – ready to use (this product is used without dilution with water)

dilution, the solution is used for daily cleaning on floors with floor finish. CM-A and CM-B are the same product, but used at different concentrations. CM-A is the use dilution for daily cleaning. CM-B is the use dilution for use as a cleaner-maintainer prior to burnishing. When this product is used at the 1:512 use dilution, it aids in soil removal from the floor finish but is not intended to provide a significant improvement in the gloss of the floor finish. When used at the more concentrated 1:256 use dilution, the product aids in restoring gloss by filling in scratches in the surface of the floor finish and prepares the finish for burnishing.

Table 2 also identifies whether a given floor maintenance product was used on a particular floor finish. In this study, all floor maintenance products were used on all of the floor finishes with the exception of SB-A, the spray buff, which is not recommended for use on Finish A or Finish D. Finishes A and D are ultra-high-speed finishes not designed to respond to low-speed buffing with a spray buff. Instead, these floor finishes require high-speed or ultra-high-speed burnishing to maintain their gloss. By including a group of floor finishes that cover the full range of floor maintenance procedures commonly used in commercial facilities, we demonstrate the complexity of matching the appropriate floor finish with floor maintenance products.

2.4 Floor layout

Because of the number of maintenance products included in this study, the study was divided into Part 1 and Part 2. Four maintenance products were tested on all finishes in each part of the study. All tiles were cleaned and stripped after initial installation to remove any mill finish from the manufacturer. The diagrams (Figs.2 and 3) indicate the tiles removed for coefficient of friction testing. Tiles in rows 1 to 6 were coated with Finish A. Tiles in rows 8 to 12 were coated with Finish B. Tiles in rows 14 to 18 were coated with Finish C. Tiles in rows 20 to 24 were coated with Finish D.

Part 1 procedure: A floor finish application expert applied the floor finishes as indicated in Figure 2, applying 4 coatings of finish to each of the tiles on a single day. The application expert ensured the application method was consistent with standard practices and the manufacturer's recommendations. The floor finish was allowed to cure overnight per the manufacturer's recommendations. The instructions on the floor finish labels used in the study indicate all the

finishes are to be applied at a rate of 490.9 cm² per ml (2000 ft²/gal). When a layer of floor finish is applied to a floor, the resultant layer of wet finish is approximately 1 mm thick. As the volatile components evaporate, which is 75 – 80 % of the formula for a typical finish, the remaining layer of cured floor finish has a height of 0.2 to 0.25 mm. When four layers of floor finish are applied to the floor and allowed to cure properly, the four layers of finish will have a height of approximately 0.8 to 1.0 mm.

	Dis-A			NC-B			SB-A			NC-A			
	1	2	3	4	5	6	7	8	9	10	11	12	
1													Finish A
2													
3		B			B			A				B	
4		B			B			A				B	
5		B			B			A				B	
6													
7	No finish on these tiles												
8													Finish B
9		B			B			B	A			B	
10		B			B			B	A			B	
11		B			B			B	A			B	
12													
13	No finish on these tiles												
14													Finish C
15		B			B			B	A			B	
16		B			B			B	A			B	
17		B			B			B	A			B	
18													
19	No finish on these tiles												
20													Finish D
21		B			B			A				B	
22		B			B			A				B	
23		B			B			A				B	
24													
25													

Figure 2. Floor layout of the tiles removed during testing in Part 1

Starting the following day, floor finish control tiles (all the tiles labelled 'A' in Figure 2) were removed, set aside for testing and replaced with spare tiles. The floor was cleaned using a TASKI Swingo 855B scrubber drier floor machine, going from top to bottom. The tiles in columns 1 to 3 were cleaned with DIS-A, columns 4 to 6 were cleaned with NC-B, columns 7 to 9 and columns 10 to 12 were cleaned with NC-A. After seven days of daily cleaning, the tiles in columns 7 to 9 were spray buffed using SB-A and a TASKI Ergodisc 200, which is a low-speed (up to 200 rpm) heavy-duty single disc floor machine used for heavy-duty floor cleaning, floor finish stripping, spray buffing and carpet shampooing. Because Finish A and Finish D are not recommended to be maintained using spray buffing, we did not test tiles with this combination. Only tiles from Finish B and Finish C were tested after spray buffing. All tiles labelled 'B' were

removed and set aside for testing in the laboratory on the James Machine either the same day or the following day. During the testing, the finished floor did not receive foot traffic, except from the person performing the daily maintenance procedure.

Part 2 procedure: After completing the testing in Part 1, approximately two months later, the tested tiles were returned to the floor and the entire floor was stripped and allowed to air dry. Floor stripping was done using a commercially available floor finish stripper following the product label directions (i.e. apply diluted stripper, allow to stand, agitate using a swing machine with a black stripping pad, wet vacuum the floor, rinse the floor with tap water and allow to air dry) and the TASKI Ergodisc 200. Vinyl composite tiles are designed to be coated with floor finish, stripped, and recoated with floor finish many times during the life of the tile. The same tiles used in Part 1 were stripped and recoated, consistent with industry practice. The floor finish coating was completed again, as in Part 1.

	CM-B			CM-A			CM-C			Dis-B			
	1	2	3	4	5	6	7	8	9	10	11	12	
1													Finish A
2													
3		B			B			B		A	B		
4		B			B			B		A	B		
5		B			B			B		A	B		
6													
7	No finish on these tiles												Finish B
8													
9		B			B			B		A	B		
10		B			B			B		A	B		
11		B			B			B		A	B		
12													
13	No finish on these tiles												Finish C
14													
15		B			B			B		A	B		
16		B			B			B		A	B		
17		B			B			B		A	B		
18													
19	No finish on these tiles												Finish D
20													
21		B			B			B		A	B		
22		B			B			B		A	B		
23		B			B			B		A	B		
24													
25													

Figure 2. Floor layout of the tiles removed during testing in Part 2

Starting the following day, finish control tiles (all tiles labelled 'A' in Figure 3) were removed, set aside for testing and replaced with spare tiles. The floor was cleaned using a TASKI Swingo 855B scrubber drier floor machine, going from top to bottom. The tiles in columns 1 to 3 and 4 to 6 were cleaned with CM-A, columns 7 to 9 were cleaned with CM-C and columns 10 to 12 were cleaned with Dis-B. This procedure was repeated for seven

days. The exception to this was that on the 7th day, the tiles in columns 1 to 3 were cleaned with CM-B in preparation for burnishing. On the 7th day, after cleaning with CM-B, the tiles in columns 1 to 3 were burnished using a TASKI Ergodisc 2000 floor burnishing machine and then the entire floor was dust-mopped to remove any dust generated by the burnishing process. All tiles labelled 'B' were removed and set aside for testing on the James Machine either the same day or the following day.

2.5 ASTM D2047 testing

Per ASTM D2047 [24], laboratory-prepared control tiles were tested to validate the James Machine before testing the floor samples. All tiles were tested over a two-day period, with Part 1 testing done roughly two months earlier than Part 2 testing. The temperature in the laboratory during testing for Part 1 was 19.7 °C (67.5 °F) on day 1 and 20.6 °C (69 °F) on day 2. The relative humidity in the laboratory was 67 % on day 1 and 56 % on day 2. The temperature in the laboratory during testing for Part 2 was 21.1 °C (70 °F) on day 1 and 21.1 °C (70 °F) on day 2. The relative humidity in the laboratory was 34 % on day 1 and 50 % on day 2. All floor tiles were left in the laboratory for at least several hours prior to testing to ensure they had reached the temperature of the laboratory environment.

ASTM D2047 was modified to allow sample tiles to be processed in the laboratory. ASTM D2047 requires all tested tiles to be prepared in the laboratory by hand-coating using a foam applicator [24]. All finish control and sample tiles removed from the magnetic floor were coated using a standard-sized floor finish applicator tool. The pass/fail criterion for ASTM D2047 requires a minimum SCOF of 0.5 [24].

2.6 Statistical analysis

For each combination of floor finish and maintenance product, three tiles were tested with four measurements per tile, giving 12 measurements per combination of finish and maintenance product, consistent with ASTM D2047 [24]. Measurements were averaged and the resulting means and standard deviations are provided in Table 3 and Figure 4. Statistical tests were also performed and are reported by floor finish. A one-way ANOVA test was performed at the 0.05 significance level. The Tukey's honest difference test was then performed at the 95 % confidence level [26] using Minitab version 21.4.2.0.

Table 3. Results by floor finish and floor maintenance product with SCOF mean values, standard deviations and Tukey groups

Floor finish	Maintenance product	Mean SCOF value and <i>SD</i>	Tukey group
Finish A	Control	0.68 (0.087)	B C
	NC-A	0.68 (0.062)	B C
	NC-B	0.69 (0.068)	B C
	Dis-A	0.66 (0.083)	C
	Dis-B	0.71 (0.039)	A B C
	CM-A	0.80 (0.040)	A
	CM-B	0.75 (0.032)	A B
Finish B	Control	0.73 (0.063)	A B C
	NC-A	0.80 (0.090)	A
	NC-B	0.70 (0.071)	B C
	Dis-A	0.70 (0.046)	B C
	Dis-B	0.70 (0.047)	B C
	CM-A	0.78 (0.051)	A
	SB-A	0.75 (0.069)	A B C
	CM-B	0.68 (0.050)	C
Finish C	Control	0.70 (0.075)	C
	NC-A	0.78 (0.067)	A B
	NC-B	0.63 (0.103)	D E
	Dis-A	0.61 (0.034)	E
	Dis-B	0.68 (0.047)	C D E
	CM-A	0.80 (0.069)	A
	SB-A	0.78 (0.065)	A B
	CM-B	0.70 (0.027)	B C D
Finish D	Control	0.76 (0.084)	A
	NC-A	0.79 (0.078)	A
	NC-B	0.76 (0.066)	A
	Dis-A	0.62 (0.063)	C
	Dis-B	0.67 (0.029)	B C
	CM-A	0.80 (0.069)	A
	CM-B	0.79 (0.056)	A
	CM-C	0.75 (0.055)	A B

Control – floor finish as applied with no maintenance procedures; *SD* – standard deviation (in parentheses)

After performing a one-way ANOVA test at the 0.05 significance level for each floor finish, the null hypothesis (all means are equal) was rejected and

the alternate hypothesis (not all means are equal) was supported due to a statistically significant difference between means. The p-values for the ANOVA test for the floor finishes are as follows: Finish A ($p < 0.0001$), Finish B ($p < 0.0001$), Finish C ($p < 0.0001$) and Finish D ($p < 0.0001$). The F-values for each floor finish are as follows: Finish A ($F = 8.37$), Finish B ($F = 5.92$), Finish C ($F = 12.82$) and Finish D ($F = 11.21$). As these F-values are all substantially larger than 1.0, when paired with statistically significant p-values, this indicates statistically significant means, justifying the use of a Tukey's honest difference test [26,27]. Additionally, we compared the 95 % confidence interval for each of the finishes prior to and after the maintenance procedures to help demonstrate whether the Tukey groups with different letter combinations were statistically different for that finish. The 95 % confidence intervals for the four floor finishes were as follows: Finish A (0.6568 – 0.7090), Finish B (0.7055 – 0.7553), Finish C (0.6760 – 0.7273) and Finish D (0.7358 – 0.7901). Lastly, to assess the study data for homogeneity, normal probability plots were generated for each floor finish (graphs not shown). All approximately followed a straight line without outliers, indicating good data homogeneity.

Depending on the floor finish and maintenance products tested, up to five distinct Tukey groups were identified (A, B, C, D and E). For a given floor finish, any group designated with a letter that is not shared by any of the other groups has a statistically significant difference from the other groups. Any group designated with two or more letters indicates that, in a pairwise comparison, it is not different from either group but is still statistically different from other groups not sharing a group letter [26].

3. Results and discussion

When the general public uses a commercial facility, they have an expectation that the floor is free of contamination and safe for walking. Some commercial facilities apply floor finishes to their floors for a range of reasons, including improved appearance, cleanability, light reflectance, and protection of the underlying floor. A floor coated with floor finish in a commercial facility requires routine maintenance, which can include the use of a range of maintenance products depending on the floor finish and the desired maintenance program. While there are standards for the slip resistance of

the floor finish, the impact of various floor maintenance practices on its slip resistance is poorly understood and not associated with specific testing standards. The slip resistance of floor finishes in many countries is expected to conform with ASTM D2047, which is tested in the laboratory using hand-coated floor tiles and the James Machine, a laboratory instrument. Once a floor finish is applied to a commercial floor, it is not practical to remove the tiles for additional testing. Thus, portable tribometers are often used to provide a measure of the slip resistance of an in-use floor at various stages of the floor maintenance cycle. Because the results from testing using portable tribometers are not calibrated against the James Machine test results, using portable tribometer results to infer whether the in-use floor coated with floor finish passes ASTM D2047 comes with some risk [7,15,21-23]. To address this issue, we conducted this study using a floor with magnetically attached floor tiles, which allows for the removal of in-use floor tiles at any desired time point.

The results of this study showed that all tested floor finish – floor maintenance product combinations passed the ASTM D2047 test and thus would be expected to provide a slip-resistant walking surface for commercial facilities. ASTM D2047 operates on a pass/fail criterion for floor finishes, requiring a minimum SCOF of 0.5 to pass the test. Individual measurements of SCOF using this test showing changes to the SCOF, especially those showing decreases in the SCOF, should be interpreted cautiously since the overall result was that all floor finish – floor maintenance product combinations passed the ASTM D2047 test criterion and passing

this standard is likely to predict a slip-resistant walking surface [20]. Burnfield and Powers [20] in their study determined that the probability of a slip on a dry unfinished floor with a coefficient of friction of 0.306 was 6 %, increasing rapidly as the coefficient of friction decreased, and commented that the 0.5 SCOF standard from the ASTM D2047 test was likely to provide an acceptable margin of safety in predicting ST&F events. Consequently, as all testing in this study showed an SCOF greater than 0.5, there appears to be little risk that floor maintenance procedures would have a practical relevance in increasing the ST&F risk for the finished floor.

For Finish A, two of the floor maintenance products (CM-A and CM-C) showed a statistically significant increase in slip resistance of the finish, while the other five products showed no statistical difference in floor finish. The two products showing the increase in slip resistance are both cleaner maintainers, suggesting their interaction with the floor finish may slightly increase the SCOF of the floor finish. The third cleaner maintainer also increased the slip resistance of the finish, but did not achieve statistical significance. None of the maintenance products tested decreased the slip resistance of the finish, so all are acceptable options for routine floor maintenance on Finish A.

For Finish B, none of the floor maintenance products showed a statistical change in the slip resistance of the finish. This floor finish appears to have minimal interaction with the range of floor maintenance products and processes and any of the tested products would be acceptable options for floor maintenance on Finish B.

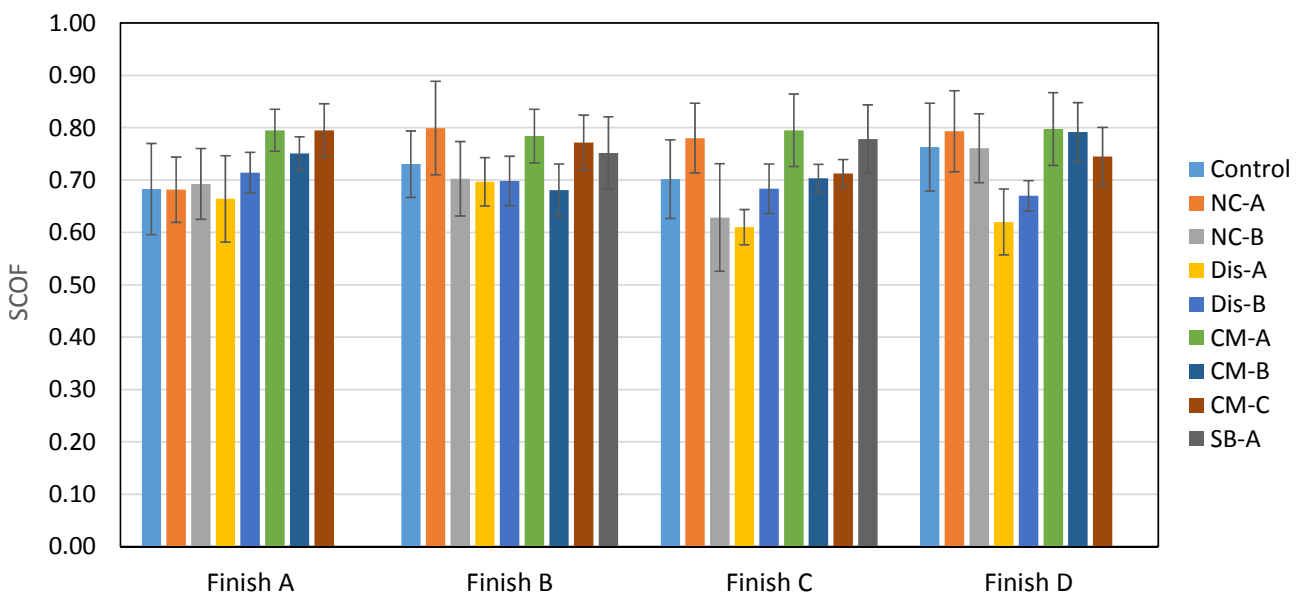


Figure 4. Mean SCOF measurements and standard deviations from ASTM D2047 testing by floor finish

For Finish C, three of the floor maintenance products (NC-A, CM-A and SB-A) showed a statistical increase in the slip resistance of the finish, two showed a statistical decrease in the slip resistance of the finish (NC-B and Dis-A) and the remaining three products (Dis-B, CM-B and CM-C) showed no statistical change in slip resistance.

The three maintenance products showing an increase in SCOF include a neutral cleaner, a cleaner-maintainer and a spray buff. The two products showing a decrease in SCOF include a neutral cleaner and a quaternary ammonium chloride (QUAT) disinfectant. Because one neutral cleaner and one QUAT disinfectant increased the SCOF of the finish and one neutral cleaner and one QUAT disinfectant decreased the SCOF of the finish, this result is harder to interpret, but reinforces the idea that finish – maintenance product interactions can be product-specific, but are unlikely to result in changes to the SCOF that create an ST&F risk.

For Finish D, none of the floor maintenance products showed a statistical increase in the slip resistance of the finish, while two products (both QUAT disinfectants) showed a decrease in slip resistance. These results suggest that the QUAT disinfectants may have an interaction with Finish D, causing the slight decrease, but still pass ASTM D2047 and thus do not create an ST&F risk.

The impact of floor maintenance practices on the slip resistance of floors coated with removable floor finish is understudied in the technical literature for a range of reasons including the challenge in measuring the slip resistance following ASTM D2047 on installed floor tiles, the wide range of maintenance products used on finished floors, the assumption that routine floor maintenance practices are unlikely to substantially impact the slip resistance of the finished floor and the difficulty in comparing portable tribometer measurements to the James Machine results. In this study, a range of eight floor maintenance products was tested on four different floor finishes for their impact on SCOF. The results of the QUAT disinfectants are noteworthy because for one of the finishes, they produced a statistically significant decrease in SCOF, but still passed ASTM D2047. For products used on floors, their interactions with different floor finishes should be investigated further.

Limitations of the study include the number of products tested, testing products from only one manufacturer, not controlling or measuring the

amount of floor finish applied with each coating, not testing at different temperatures and humidities, using a single expert floor care application expert to apply the finish, only performing the routine floor maintenance for seven days and using only one floor machine of each type. Additionally, while ASTM D2047 requires the use of a foam-tipped applicator (similar to a small paintbrush), a commonly used floor finish applicator tool and pad were used to apply the finish for the study, as would be done in the real world. This may introduce variation versus running ASTM D2047 with laboratory-prepared samples. This concern is somewhat mitigated by a prior study by our laboratory [25], which showed that increasing the amount of floor finish does not reduce the SCOF of the finished floor. Testing on only one flooring type may also be a limitation, but when a floor is coated with floor finish, slip resistance testing is performed primarily on the topmost layer of the floor finish, limiting the impact of the flooring material. As long as the floor finish properly adheres to the flooring material, the flooring choice appears to have little impact on the slip resistance of the finished floor. Regardless, there is a benefit to testing additional floor finishes, additional maintenance products and additional flooring materials. These factors may influence the results and deserve additional investigation in the future.

4. Conclusion

In summary, this study found that the floor maintenance product used on a finished floor can decrease, increase or have no statistically significant impact on the slip resistance of the floor finish, as measured by the James Machine using ASTM D2047, and that this impact was specific to the maintenance product and floor finish interaction. Even when this interaction results in a decrease in SCOF, this resulting change is unlikely to change the SCOF to a point where an ST&F event is likely to occur.

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