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Vinyl Composite Tile Surrogate for Mechanical Slip Testing

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Abstract

Background: Vinyl composite tile (VCT), which is a common flooring in workplaces, is sometimes utilized as the standard floor material for mechanical slip testing experiments. Unfortunately, VCT is a sub-optimal standard test material, since it changes over time and is difficult to manufacture consistently.

Purpose: This study aimed to identify a durable laboratory-grade substitute flooring that could provide traction results that are representative of footwear performance on VCT.

Methods: Eight polymer tiles (cast nylon, polyethylene, polycarbonate, acetal, Delrin, PTFE, polypropylene, and nylon) were tested and the available coefficient of friction (ACOF) was measured and compared with that of two VCT designs. First, a screening test was performed to identify good material candidates based on six shoes and two contaminants (water and oil). Two surrogate candidate tiles were then tested across 17 shoes and three contaminant conditions (water, sodium laurel sulfate, and oil).

Results: Cast nylon tile was found to be the most generalizable VCT surrogate, exhibiting strong correlations with both VCTs for oil contamination. None of candidates were representative of the VCTs for other contaminants.

Conclusions: Cast nylon may be a useful alternative for VCT for standard slip testing of footwear in oily conditions.

Keywords

Slip; Traction; Coefficient of Friction; Vinyl composite tile; Footwear

1. Introduction

Falls due to slipping are a common cause of injuries (Courtney, Sorock, Manning, Collins, & Holbein-Jenny, 2001; Strandberg & Lanshammar, 1981). In 2016, over 25,000 fall injuries

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Conflict of Interest
The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

were reported in the US on a daily basis according to the National Safety Council (NSC), costing more than $70 billion in medical expenses (Di Pilla, 2016). In the United States, the non-fatal fall incidence rate was 23.1 per 10,000 full time employees, and 887 workers died from a fall (U.S. Department of Labor-Bureau of Labor Statistics, 2018a, 2018b). Slipping is caused by poor friction or traction at the shoe-floor interface (Redfern et al., 2001; Strandberg & Lanshammar, 1981). Shoes are typically tested using slip testing devices across standard floorings in dry and contaminated conditions in order to assess their traction performance (Beschorner, Iraqi, Redfern, Cham, & Li, 2019; Chang et al., 2001; Iraqi, Cham, Redfern, & Beschorner, 2018). These devices measure the available coefficient of friction (ACOF) at the shoe-floor interface. Standard floorings are sometimes used to maintain consistent flooring interface, while the shoe sample is changed (Jones, Iraqi, & Beschorner, 2018). One example of a standard flooring is vinyl composite tile (VCT), which is used as a reference tile by ASTM standard ("ASTM F2508–12a: Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces," 2012). Another use of standard tiles is to validate their instrument's ability to rank traction performance consistent with human-slip responses (Powers, Blanchette, Brault, Flynn, & Siegmund, 2010).

VCTs are often installed in commercial settings such as offices, restaurants, and hospitals, where high traffic is expected, or where a clean environment is desired (Jones, 1999). A recent study (Chanda, Jones, & Beschorner, 2018) on the footwear traction performance testing on VCT and quarry floorings revealed strong correlation across VCT tiles tested with the same contaminant. Thus, a surrogate tile that correlates well with one VCT design is likely to correlate well with others.

Wet VCT has been observed to wear quickly and produce inconsistent traction testing results with long term use (Nemire, Johnson, & Vidal, 2016), the compared to standard reference ceramic and quarry tiles (ANSI/ASSE, 2007). Substantial variation has been observed in traction across samples (in the range of 0.12–0.27), and testing locations (in the range of 0.15–0.25) on the same VCT tile (Nemire et al., 2016; Newsletter, 2013). Installed VCT requires significant maintenance (waxing/stripping) to prevent moisture from being absorbed into the tile (Frank, 2002). We are unaware of any established methods to ensure the maintenance of VCT tiles used in traction testing. In light of these limitations, it was considered valuable to identify a potential laboratory-grade material that can be a VCT surrogate. To accomplish this goal, we investigated the traction performance of several commercial-grade polymer-based floor tiles and their correlation with two VCT designs (Chanda et al., 2018). The ACOF of different shoes were characterized on these tiles across different contaminant conditions using a biofidelic slip tester. The purpose of this study was to identify a tile that exhibits strong correlations in shoe traction with two VCT designs.

2. Materials and Methods

ACOF tests were conducted using a biofidelic slip tester in two phases. In the first phase, eight flooring candidates were tested with six shoe designs and two contaminant conditions. The second phase tested two floorings (selected based on the first phase) with 17 shoes and three contaminant conditions. A total of 990 test trials were conducted, over a period of 31 days.

2.1 Shoes, floorings and contaminants

The shoes were procured from 10 different brands to cover a wide range of those which are commonly worn in indoor workplaces. A total of 17 shoes were selected, including six Oxford-style work shoes, seven comfort shoes, one athletic shoe, and three clogs. Twelve of the shoes were labeled as slip-resistant (SR) and five did not include this label (NSR). The NSR shoes were selected because they were commonly used in place of SR shoes in occupational environments (Table 1). All of these shoes have been tested previously (Beschorner, Jones, & Iraqi, 2017; Chanda et al., 2018). All of the shoes were U.S. Men's size 9 right shoes, except shoe number 9 which was a Women's size 10 right shoe. For the first phase of testing, six shoes (Shoe No. 1, 2, 7, 11, 14, and 15 in Table 1) were selected out of the 17 shoes. For the second phase, all 17 shoes were tested.

Eight polymer-based tiles were considered in the study. The tiles were part of a larger study at the National Floor Safety Institute that aimed to identify calibration tiles for flooring traction testing. These tiles are laboratory-grade materials from different plastic families, with different material compositions, manufacturing processes, and physical properties (Table 2) (D4000–16, 2016). Except for Polycarbonate, which is an amorphous thermoplastic, all of the other seven tiles are semi crystalline thermoplastics with good fatigue, wear, and chemical resistance (Rosato, Rosato, & v Rosato, 2004). Two vinyl composite tiles (VCTs) were selected for comparison of the traction performance of the eight tiles. One of these two VCTs ("ref vinyl") was a reference tile from the ASTM F2508 standard ("ASTM F2508–12a: Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces," 2012). The other VCT ("lab vinyl") tile was selected as it was installed in a gait laboratory for human subject slipping experiments Jones et al., 2018. The testing of both VCTs was described previously (Chanda et al., 2018). For all 10 floorings, surface roughness measurements (R_z) were conducted (Table 2) at different orientations and locations, using a 2D contact profilometer (Surtronic S-100, Taylor-Hobson, AMETEK, Leicester, England). For the first phase of testing, all eight tiles were used. The tiles that were included in the second phase depended on the results of the first phase.

Three contaminants were tested, including water, a mixture of sodium laurel sulfate (SLS; 0.5% by volume) and water (99.5% by volume), and canola oil (referred as "oil" in the following sections). The viscosities of these contaminants measured using a rheometer (Table 3) (Brookfield AMETEK LVDVE115 with spindle UL/Y, Middleboro, MA). In the first phase of testing, only water and oil were tested to represent a wide range of contaminant viscosities. This was followed by testing of all three contaminants in the second testing phase.

2.2 Mechanical traction testing framework

To simulate footwear slipping on a contaminated flooring and to quantify ACOF, a portable, biofidelic slip tester was used. This slip tester is based on the previous work by Aschan et al.

(2005), and has been successfully used in other research to assess footwear (Chanda et al., 2018; Iraqi et al., 2018 Jones et al., 2018). The major components of this device include three parallel linear servomotors (LinMot USA PS01-37X240, Lake Geneva, WI, USA) to produce vertical forces, and one similar motor (LinMot USA PS01-48X240, Lake Geneva, WI, USA) to produce horizontal forces and generate the sliding movement (see Figure 1). This slip tester has an attachment for a shoe last and a mechanism for adjusting the angle between the shoe and floor (Figure 1). A force plate (Bertec FP4060, Columbus, OH) was used for measuring the normal and shear forces generated during a traction test. The ambient conditions of the lab environment were maintained throughout the testing process by an HVAC system.

For conducting a traction test, a sufficient amount of contaminant was applied to the floor tile to fully cover the surface (Chanda et al., 2018) and to reach the maximum film thickness for the floor lubricant interface. The amount of glycerol was not controlled, since the maximum film thickness is dependent on the interfacial surface energy of the contacting tile and contaminant, and not the contaminant volume (Shibata et al., 2019). The shoe loading conditions were selected based on an earlier study of the dynamics of the heel during slips (Chanda et al., 2018), and are a part of an ANSI draft standard (ANSI/NFSI B101.7–2018) under consideration.

A shoe-floor angle of 17 ± 1° was used throughout testing. A normal force of 250 N was applied using the vertical motors, and a horizontal force was applied with the horizontal motor simultaneously to generate a sliding speed of 0.5 m/s. As soon as the normal force first reached a value of 250 N, it was maintained within the ±25 N range for 200 ms. The normal and friction forces were quantified during this time interval, and ACOF was calculated as the mean ratio of friction force to normal force (Figure 2). Five trials were conducted for each test condition, and the mean ACOF was obtained across the five trials. After each trial, the contaminant was redistributed such that it covered all of the asperity peaks (i.e., a flooded condition). Between each contaminant condition tested, a thorough cleaning was performed on the floor with water and detergent, followed by rinsing and drying. It should be mentioned that in a few test conditions, a slip-stick phenomenon was observed, where the shoe alternated between sticking to the floor and sliding, causing a change to the normal and horizontal forces. In these cases, the normal force was outside of the 250 ± 25 N range.

2.3 Statistical analyses

Pearson correlation analysis was performed for the ACOF values of shoes measured across each of the eight commercial grade polymer-based tiles, and the two VCTs (i.e., ref vinyl and lab vinyl), for each contaminant. The quality of correlation between any two floorings was described using the coefficient of determination (r^2), and these were interpreted as low (or weak) and high (or strong) for values below and above a threshold of r^2=0.5, respectively.

The first phase of testing was conducted to identify two out of the eight polymer-based tiles, which exhibit the strongest correlation with the VCTs (i.e., potential VCT surrogates), for water and oil based on data from six shoes. This phase was intended to screen the surrogates for strong candidates. For the second phase, one out of the two potential VCT surrogates was selected as the best VCT surrogate based on the strongest correlations observed with the VCTs from testing with 17 shoes and three contaminants (i.e., water, SLS and oil). For each comparison, a *t*-test was performed, assessing the null hypothesis that the slope of the best fit line equals zero. A total of 32 *t*-tests were conducted for first phase testing. Due to a high number of parameters analyzed, a Bonferroni correction was implemented (α = 0.05/32 = 0.0015; 8 candidate tiles × 2 VCTs × 2 contaminants). For the second phase testing, 12 *t*-tests were conducted. A Bonferroni correction was implemented again (α = 0.05/12 = 0.004; 2 candidate tiles × 2 VCTs × 2 contaminants) In addition, *z*-tests were performed to compare the correlation coefficients between the two candidate tiles, to determine if one candidate tile had a stronger correlation with VCT than the other candidate. Since six comparisons were made (2 VCTs × 3 contaminants), a Boneforroni correction was made (α = 0.05/6 = 0.0083).

3. Results

3.1 Phase 1: Screening for Surrogate Candidates

The range of ACOF values measured was 0.27–0.97 for water contamination, and 0.06–0.44 for oil contamination (Table 4). Across shoes and with water contamination, the highest and lowest mean ACOFs of 0.75 and 0.45 were measured for shoes 2 and 7, respectively. With oil contamination, the highest and lowest mean ACOFs were 0.26 and 0.07, respectively. Across tiles, the highest and lowest mean ACOFs with water contamination were observed for PTFE (ACOF=0.71) and polycarbonate (ACOF=0.46) tiles, respectively. For oil contamination, mean ACOF values on all candidate tiles were similar, in the range of 0.11–0.14, except for cast nylon (ACOF=0.23). The standard deviations in ACOF values across trials for any condition was typically low. For water contamination, the standard deviation ranged between 0–0.09. Standard deviations in the range of 0–0.01 were observed for oil contamination tests. Repeatability tests were not considered separately due to these low standard deviation values.

With water contamination, ACOF correlations between the surrogate candidate tiles and the VCTs (i.e., ref vinyl and lab vinyl) were highly variable. Figure 3 (left) illustrates an example of weak correlation (r^2=0.002, p=0.93, $t(5)$=0.08) between ACOFs of shoes for Delrin and standard VCT tile (i.e., ref vinyl), with water contamination. Weak correlations were observed (Figure 4) between the ACOF values of standard VCT and most of the surrogate candidate tiles under water contaminated conditions (i.e., Cast nylon, UHMW polyethylene, acetal copolymer, Delrin, polycarbonate, polypropylene, and H-D Nylon, r^2<0.25). The strongest correlation (r^2=0.64 p=0.05, $t(5)$=2.67) with water contamination was recorded between standard VCT and PTFE. Weak ACOF correlations (r^2<0.48) were observed between the other VCT (i.e. lab vinyl) and all surrogate candidate tiles (Figure 4). The highest correlations with the other VCT was observed for cast nylon (r^2=0.48 p=0.13, $t(5)$=1.92) followed by H-D Nylon (r^2=0.47 p=0.13, $t(5)$=1.91). Relatively similar correlations were observed for UHMW polyethylene, acetal copolymer, PTFE, and polypropylene with the other VCT (Figure 4). Overall, Delrin and polycarbonate were found to be the least correlated (r^2<0.12) with both VCTs for water contamination.

With oil contamination, strong correlations (r^2>0.71) were observed between ACOF of shoes on the surrogate candidate tiles, and ACOF of shoes tested on the VCTs (see Figure 5). Figure 3B shows an example of a strong correlation (r^2=0.75, p<0.05, $t(5)$=3.46) between ACOF of the shoes for UHMW polyethylene and standard VCT, with oil contamination. For the standard VCT, the strongest ACOF correlations were observed for PTFE (r^2=0.95 p=0.5, $t(5)$=8.78) followed by cast nylon (r^2=0.89 p<0.001, $t(5)$=8.78). With the other VCT, the strongest correlation was observed with cast nylon (r^2=0.96, p<0.001, $t(5)$=9.67) followed by similar correlations for Delrin and PTFE (0.87<r^2<0.88, p<0.05).

In order to select two potential surrogate tiles for the VCTs, their correlations with all the candidate tiles were compared (Figures 4 and 5). For water contamination, the correlation of the tiles with one VCT was not consistent with that of the other VCT. Even though PTFE exhibited the highest correlation with the standard VCT, and cast nylon and H-D Nylon with the other VCT, these correlations were still not very strong (0.47<r^2<0.64). With oil contamination, the strongest correlation with the standard VCT was observed for PTFE (r^2=0.95) followed by cast nylon (r^2=0.89). With the other VCT, the highest correlations were with cast nylon (r^2=0.95), followed by Delrin (r^2=0.88) and PTFE (r^2=0.87). As cast nylon had consistently higher correlations than the rest of the tiles (except PTFE) with both VCTs for oil contamination, it was selected as a potential VCT surrogate. For the second potential surrogate selection, PTFE was found to exhibit consistently strong correlations with both VCTs. Delrin, on the other hand, had a weaker correlation than PTFE with the standard VCT, and an almost similar correlation as PTFE with the other VCT. Therefore, out of the two, PTFE was determined as the better candidate for a VCT surrogate.

3.2 Phase 2: ACOF correlations of VCT surrogate candidates and VCTs

The correlation results between the surrogate candidates and VCT tiles were not particularly strong (r^2<0.55) in the presence of both water and SLS contaminants. Also, with either of these contaminants, the rank of the correlation (i.e., the surrogate with a higher correlation) was inconsistent across the two VCTs (Figure 6). However, for oil contamination, the cast nylon exhibited stronger correlations than PTFE, with both VCTs. Specific correlations quantified for cast nylon were (r^2=0.77, p<0.001, $t(16)$=7.15) with the standard VCT and (r^2=0.90, p<0.001, $t(16)$=12.0) with the other VCT. The cast nylon had a stronger correlation with the Other VCT compared with the PTFE (z=2.69, p=0.007). The two tiles had similar correlation in all other conditions.

4. Discussion

This study evaluated different laboratory-grade polymer substitutes to identify a VCT surrogate. With water and SLS contaminations, the correlations between most of the candidate tiles and the VCTs were weak. Across tiles with oil contamination, the highest and most consistent correlations with the two VCTs were observed for cast nylon. Therefore, it was concluded that the traction performance of cast nylon on oil was generalizable with the oil-covered VCTs. These results provide important information, which can guide standard substitutes for VCT flooring. Our results are somewhat similar with the literature. In a recent study, Chanda et al. (2018) investigated the generalizability of traction performance of shoes across quarry floorings and VCTs, with different contaminants. Lower ACOF correlations were observed across tiles for water and SLS contaminations than for oil.

This study may provide insights into the role of surface topography and material composition when selecting a surrogate material. Interestingly, the two materials (cast nylon and PTFE, Table 2) with the strongest correlations to oily VCT also had the most similar mean peak-to-valley roughness (Rz) as the VCT designs. Hysteresis friction is known to be the dominant friction mechanism at the shoe-floor interface in oily conditions and is known to be sensitive to floor roughness (Cowap, Moghaddam, Menezes, & Beschorner, 2015; Moghaddam & Beschorner, 2018; Moghaddam, Hemler, Redfern, Jacobs, & Beschorner, 2019). Thus, it is not surprising that candidate tiles with similar roughness to VCT correlated well with VCT in the presence of oil. In the presence of water or SLS, adhesion forces tend to contribute to the overall friction (Cowap et al., 2015; Strobel, Menezes, Lovell, & Beschorner, 2012). Adhesion is dependent on intermolecular forces. The amount of adhesion is sensitive to the real area of contact (which is also sensitive to surface roughness) as well as the ability of the two surfaces to form an adhesive bond (Bhushan, 2013). None of the surrogates appeared to mimic VCT's ability to generate adhesion forces with the shoes. One possible reason is that only two of the surrogates had similar topography as the VCTs, and these two surrogates may not have mimicked VCT's ability to bond with shoe outsole materials. Thus, additional research is needed to identify a surrogate for VCT in the presence of water (such as the case for the ASTM F2508 standard ("ASTM F2508–12a: Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces," 2012)) Future studies may want to give further consideration to the molecular structures of potential polymer surrogates to improve their ability to mimic VCT adhesion forces.

The current work has a few limitations. Only a subset of the vast number of floors and contaminant conditions were considered. While previous research suggests that performance on one VCT design is applicable to others (Chanda et al. 2018), testing additional designs would clarify this relationship. Characterizing the consistency of traction performance of shoes measured across multiple samples of this surrogate tile, and across different directions, would be needed to assess the reproducibility of these tiles. Also, the consistency of this surrogate tile across different manufacturers needs to be quantified. Furthermore, the consistency of slip testing results of shoes on this surrogate tile, measured across different slip testers, needs additional investigation. Lastly, we did not systematically modify material composition and roughness. Thus, it remains unclear whether the results are due to topography or the materials. Future studies will focus on understanding the traction performance of shoes measured on the surrogate tile and its generalizability across a wide range of VCTs (used in oil contaminated areas such as kitchens). Also, intra-tile variabilities will be characterized for the surrogate, for batches purchased from the same and different manufacturers, and the effect of testing across different directions will be investigated.

In conclusion, this study generated important information on the generalizability of slip resistance of laboratory-grade polymer tiles relative to VCTs for different contaminations. A high fidelity surrogate cast nylon was identified for the VCTs, for oil contamination specifically. This knowledge can lead to environmental fidelity with respect to traction performance of VCT floorings, while addressing concerns of durability and consistency. Further, the surrogate VCT tile could be adopted as a standard flooring material for assessing slip risk for shoes that are likely to be used on oily VCT, such as in restaurants and kitchens.

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U.S. Department of Labor-Bureau of Labor Statistics. (2018b). TABLE R8. Incidence rates for nonfatal occupational injuries and illnesses involving days away from work per 10,000 full-time workers by industry and selected events or exposures leading to injury or illness, private industry, 2017. Washington, D.C. Retrieved from https://www.bls.gov/iif/oshwc/osh/case/cd_r4_2017.htm.

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Occupational Applications

This study aimed to identify a durable laboratory-grade surrogate material for vinyl composite tile (VCT) suitable for footwear traction testing. To conduct this investigation, eight polymer tiles (cast nylon, polyethylene, polycarbonate, acetal, Delrin, PTFE, polypropylene, and nylon) were tested across different shoes and contaminants (water, sodium laurel sulfate, and oil), and the available coefficient of friction (ACOF) was measured and compared with that of two designs of VCT. Shoe ACOF performance on cast nylon tile with oil contamination was generally applicable to both VCTs in oil contaminated condition. Shoe ACOF performance for none of the eight candidate tiles were applicable to the VCTs for other contaminated conditions. Cast nylon is anticipated to serve as a durable VCT surrogate, for standard slip testing of footwear in oil contaminated conditions.

Figure 1:
Portable slip tester for mechanical testing, using a set-up similar to (Chanda et al., 2018)

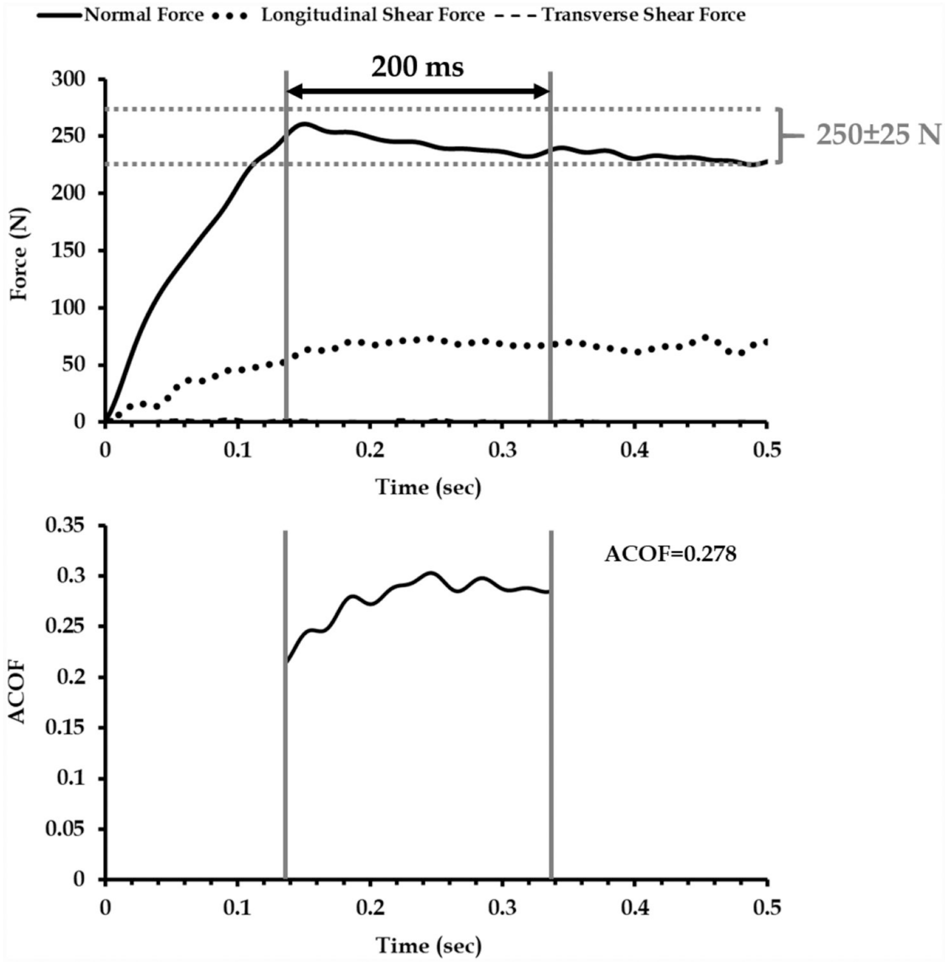

Figure 2:

Representative forces and ACOF measured in a traction testing trial for 200 ms after the normal force exceeded 250 N

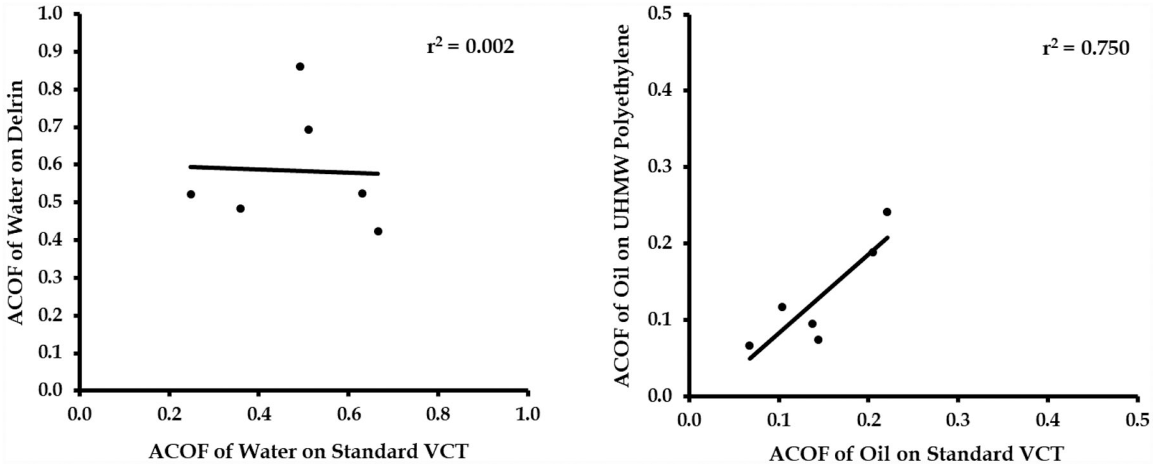

Figure 3:
Mean ACOFs of 6 shoes (each tested 5 times) with the same contamination, correlated between floorings: left) Delrin and standard VCT with water, and right) UHMW polyethylene and standard VCT with oil

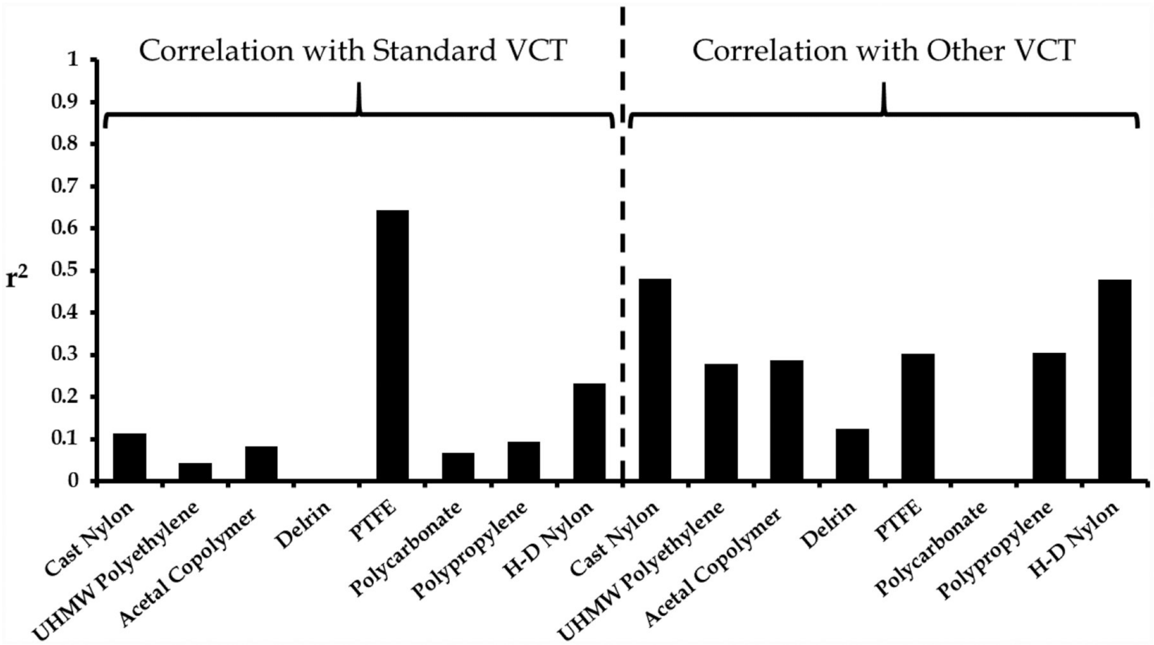

Figure 4:
Coefficient of determination across surrogate candidates and standard ref VCT surface (left) and the other lab VCT (right). These results are for water contamination and are based on 6 shoes (mean of 5 repeated tests for each case)

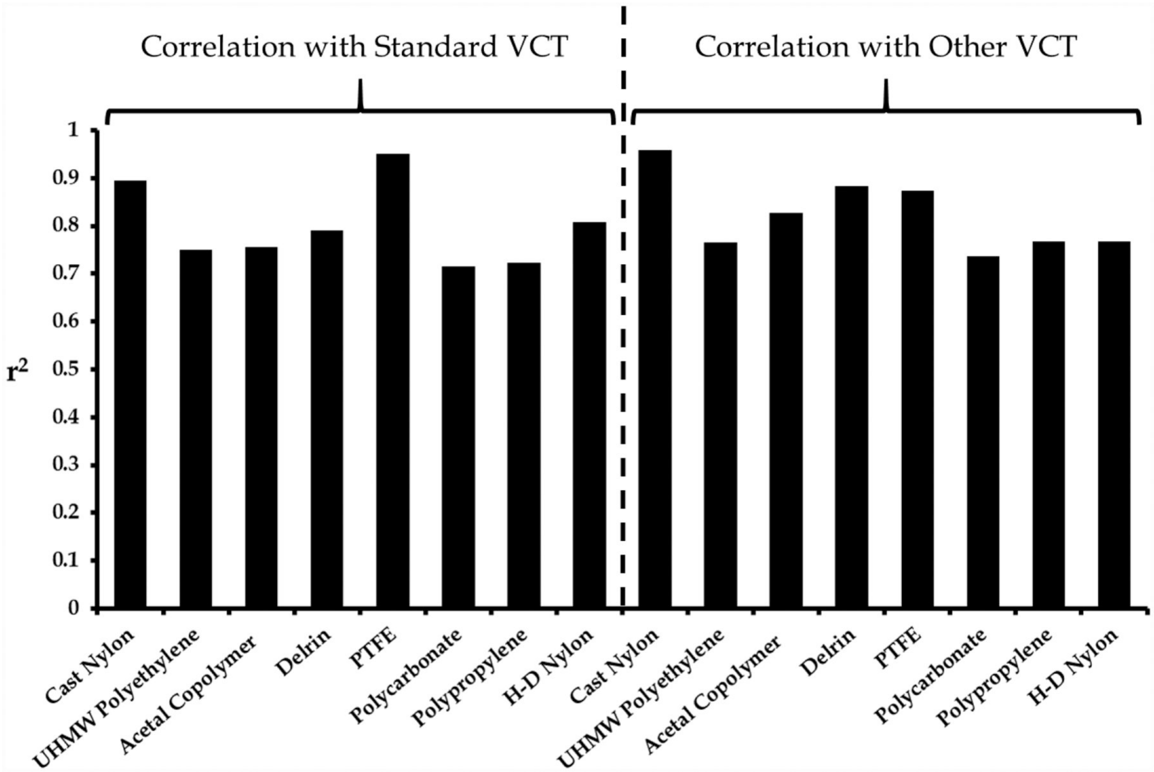

Figure 5:

Coefficient of determination across surrogate candidates and standard ref VCT surface (left) and the other lab VCT (right). These results are for oil contamination and are based on 6 shoes (mean of 5 repeated tests for each case)

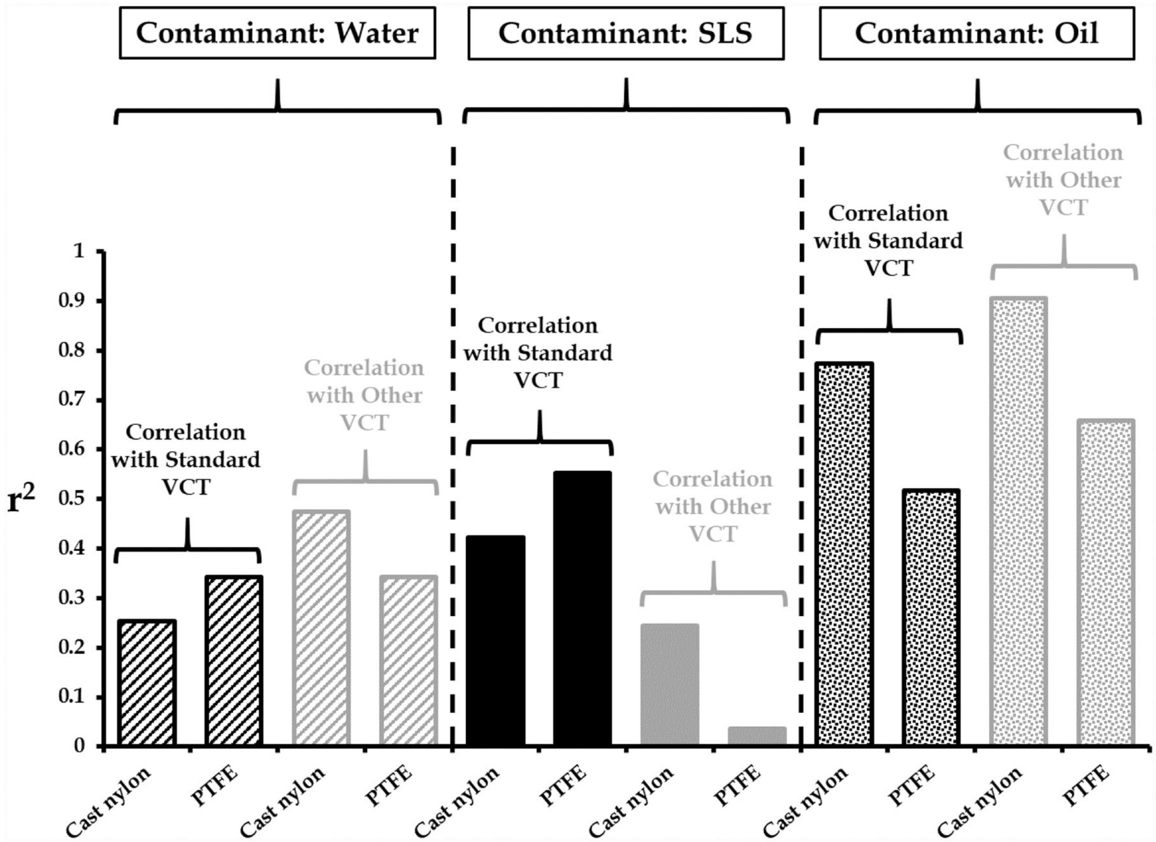

Figure 6:

Coefficient of determination across surrogate candidates (i.e. cast nylon and PTFE) and standard ref VCT surface (dark) and the other lab VCT (grey). These results are for water, SLS, and oil contaminants, and are based on 17 shoes (mean of 5 repeated tests for each case)

Table 1:

Shoe specifications including shoe number, brand, model, style, and SR (Slip Resistant) or NSR (Non Sip Resistant) designation

Shoe No.	Shoe Brand	Shoe Model	Shoe Style	SR/NSR Designation
1	SR Max	*SRM3500*	Dress	SR
2	Shoes for Crews	*Cambridge 6006*	Dress	SR
3	Keuka	*Equity 5000*	Dress	SR
4	SafeTstep	*Able 151864*	Dress	SR
5	SR Max	*SRM6200*	Comfort	SR
6	Shoes for Crews	*Freestyle 6010*	Comfort	SR
7	Keuka	*Galley 55014*	Comfort	SR
8	SafeTstep	*Apollo 140060*	Comfort	SR
9	Tredsafe	*M151044BU*	Comfort	SR
10	SR Max	*SRM7500*	Clog	SR
11	Tredsafe	*M151045AD*	Clog	SR
12	ECCO	7582583	Dress	NSR
13	Converse	IT865	Comfort	NSR
14	Nike	705149010	Athletic	NSR
15	TOMS	001001B07	Comfort	NSR
16	Crocs	203261	Clog	NSR
17	Tredsafe	*MNTS0541002*	Dress	SR

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Table 2:

Specification of eight flooring tiles and two VCTs including surface roughness means (standard deviation)

Tile Material	Standard	Surface Roughness (μm), Rz
Cast nylon	ASTM D4066	13.5 (8.23)
UHMW polyethylene	ASTM D4020	1.75 (0.46)
Acetal Copolymer	ASTM D6100	3.62 (4.02)
Delrin ®	ASTM D4181	1.06 (0.62)
Polytetrafluoroethylene (PTFE)	ASTM D4894/4895	14.7 (7.06)
Polycarbonate	ASTM D3935	0.68 (0.37)
Polypropylene	ISO 4577	1.25 (0.65)
High-Density (H-D) Nylon	ASTM D4066	1.37 (0.44)
"Ref Vinyl"	ASTM F2508	11.3 (1.12)
"Lab Vinyl" *(Armstrong 51804)*	N/A	13.7 (2.31)

Table 3:

Specifications of contaminants tested including viscosity means (standard deviation)

Contaminant	Viscosity (cP)
Water	0.98 (0.01)
SLS	1.21 (0.02)
Canola oil	65.4 (0.20)

Table 4:

ACOFs of shoes tested on eight polymer-based tiles with water and oil contaminants. For each shoe-tile combination, the tests were repeated 5 times, and means (standard deviation) are presented

	Water Contaminant							
Shoe No.	***Cast Nylon***	***UHMW Polyethylene***	***Acetal Copolymer***	***Delrin***	***PTFE***	***Polycarbonate***	***polypropylene***	***H-D Nylon***
1	0.61(0.00)	0.68(0.01)	0.81(0.01)	0.42(0.02)	0.56(0.00)	0.78(0.02)	0.65(0.01)	0.77(0.01)
2	0.69(0.00)	0.82(0.03)	0.79(0.02)	0.69(0.01)	0.52(0.00)	0.83(0.03)	0.91(0.00)	0.73(0.01)
7	0.47(0.00)	0.37(0.00)	0.57(0.02)	0.48(**0**.05)	0.27(0.01)	0.65(0.00)	0.42(0.00)	0.35(0.02)
11	0.85(0.05)	0.97(0.04)	0.72(0.02)	0.86(0.05)	0.35(0.01)	0.69(0.02)	0.76(0.04)	0.52(0.01)
14	0.56(0.01)	0.6(0.02)	0.56(0.02)	0.52(0.02)	0.67(0.03)	0.51(0.02)	0.65(0.01)	0.29(0.00)
15	0.51(0.01)	0.68(0.02)	0.67(0.01)	0.52(0.02)	0.36(0.01)	0.78(0.09)	0.64(0.02)	0.34(0.01)
	Oil Contaminant							
Shoe No.	***Cast Nylon***	***UHMW Polyethylene***	***Acetal Copolymer***	***Delrin***	***PTFE***	***Polycarbonate***	***polypropylene***	***H-D Nylon***
1	0.44(0.01)	0.24(0.00)	0.25(0.00)	0.25(0.00)	0.17(0.00)	0.23(0.00)	0.23(0.00)	0.28(0.01)
2	0.32(0.00)	0.19(0.00)	0.18(0.00)	0.17(0.00)	0.15(0.00)	0.18(0.00)	0.17(0.00)	0.21(0.00)
7	0.18(0.00)	0.07(0.01)	0.07(0.00)	0.08(0.00)	0.09(0.00)	0.07(0.00)	0.07(0.00)	0.07(0.00)
11	0.22(0.00)	0.10(0.00)	0.10(0.00)	0.09(0.00)	0.11(0.00)	0.10(0.00)	0.09(0.00)	0.11(0.00)
14	0.11(0.00)	0.07(0.00)	0.07(0.00)	0.07(0.00)	0.07(0.00)	0.06(0.00)	0.06(0.00)	0.06(0.00)
15	0.13(0.00)	0.12(0.00)	0.10(0.00)	0.09(0.00)	0.08(0.00)	0.13(0.00)	0.11(0.00)	0.09(0.00)