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TECHNICAL NOTE

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Influence of Groove Count on Slip Resistance Using NTL Test Feet

ABSTRACT: In recent years, walkway slip-resistance testing with grooved NTL (Neolite® Test Liners) has been the subject of research, as well as used in field investigation practices. Recent research shows that differences between non-grooved and grooved test feet do exist, especially under wet conditions. It is not known how the number of grooves influences the slip resistance. This study investigates the influence of groove count on slip resistance under both wet and dry conditions using the PIAST tribometer. Test feet with 1, 3, 5, 7, 9, 11, 13, and 15 grooves and a non-grooved test foot were used. Polished granite and vinyl composition tile were used as test surfaces. Results for both test surfaces show markedly higher slip resistance for increasing groove counts under wet conditions, while under dry conditions, the results show slight increases in slip resistance. Implications of these results are discussed.

KEYWORDS: forensic science, NTL (Neolite® Test Liner), slip resistance, tribometry, walkway safety

The slip resistance of walkway surfaces is of significant concern in minimizing the chance of slip-and-fall mishaps. [Authors' note: for the purpose of this paper, the term slip resistance is used synonymously with the term coefficient of friction] Slip resistance is quantified using one of several instruments referred to as tribometers (1) A particular type of tribometer used for measuring slip resistance under dry and wet conditions is the Portable Inclinable Articulated Strut Tribometer (PIAST) shown in Fig. 1. The primary concept behind this instrument involves applying vertical and horizontal forces simultaneously to the flooring surface by means of a descending test foot. Any number of materials for the test foot, including actual shoe soling materials can be used. Neolite® (obtained from Smithers Scientific Services, Inc. Akron, Ohio; www.smithers-scientific.com) has, however, become a commonly used and accepted material in test feet for slip-resistance testing and is commonly referred to as Neolite® Test Liner (NTL). NTL is a synthetic material considered by many to be appropriate for slip-resistance testing due to several desirable characteristics, including consistency, wear-resistance, and low water absorbency.

Since the original introduction of NTL test feet in slip-resistance testing, test feet have been constructed with no pronounced textures or groove patterns (smooth) (2). At times, grooves have been introduced into a test foot for the purpose of emulating a "tread pattern" on the bottom of the shoe. The only known groove pattern is fifteen grooves evenly machined parallel to the direction that the test foot moves during slippage. These grooved test feet are not meant to replace the non-grooved test feet, but grooved NTL test feet may better reflect the slip resistance of shoe soles with tread patterns. There is limited published data on the effects of these grooved NTLs on slip resistance. To date, the authors are aware of only one published paper which has investigated the influence of grooves on slip resistance. Medoff, et al. investigated a non-grooved NTL and a 15-grooved NTL on quarry and ceramic tile surfaces in both the wet and dry conditions using a PIAST and another commonly used tribometer (3). Their study shows marked increases of slip resistance under wet conditions while the results are mixed under the dry condition. One could infer that the increase of slip resistance with grooved test feet is due to the ability of the grooves to channel the water (or other interface contaminants) away, in effect, minimizing or eliminating hydroplaning, thus allowing the test foot to better contact the flooring surface. Under dry conditions, their study shows mixed differences between the grooved and non-grooved test feet.

Although, as indicated above, previous researchers have reported that 15-grooved NTL test feet will influence slip resistance, especially under wet conditions (3), there has not yet been a quantitative study of the relationship between slip resistance and the number of grooves. The purpose of the present study is to investigate the relationship between the number of grooves in an NTL test foot and slip resistance. Specifically, grooved NTL test feet with 1, 3, 5, 7, 9, 11, 13, and 15 grooves, along with a non-grooved test foot, are compared on two different test surfaces: polished granite and vinyl composition tile (VCT), under both dry and wet conditions. The non-grooved, 5-grooved and 15-grooved test feet, respectively, are shown in Fig. 2. We hypothesize that the grooved test feet will show increased slip resistance under wet conditions with an increased number of grooves. Additionally, we hypothesize that the slip-resistance values will also show differences across the different grooved test feet under dry conditions.

Methods

Testing was conducted at the laboratory facilities of ARCCA, Inc., in Penns Park, Pennsylvania. Environmental conditions at the

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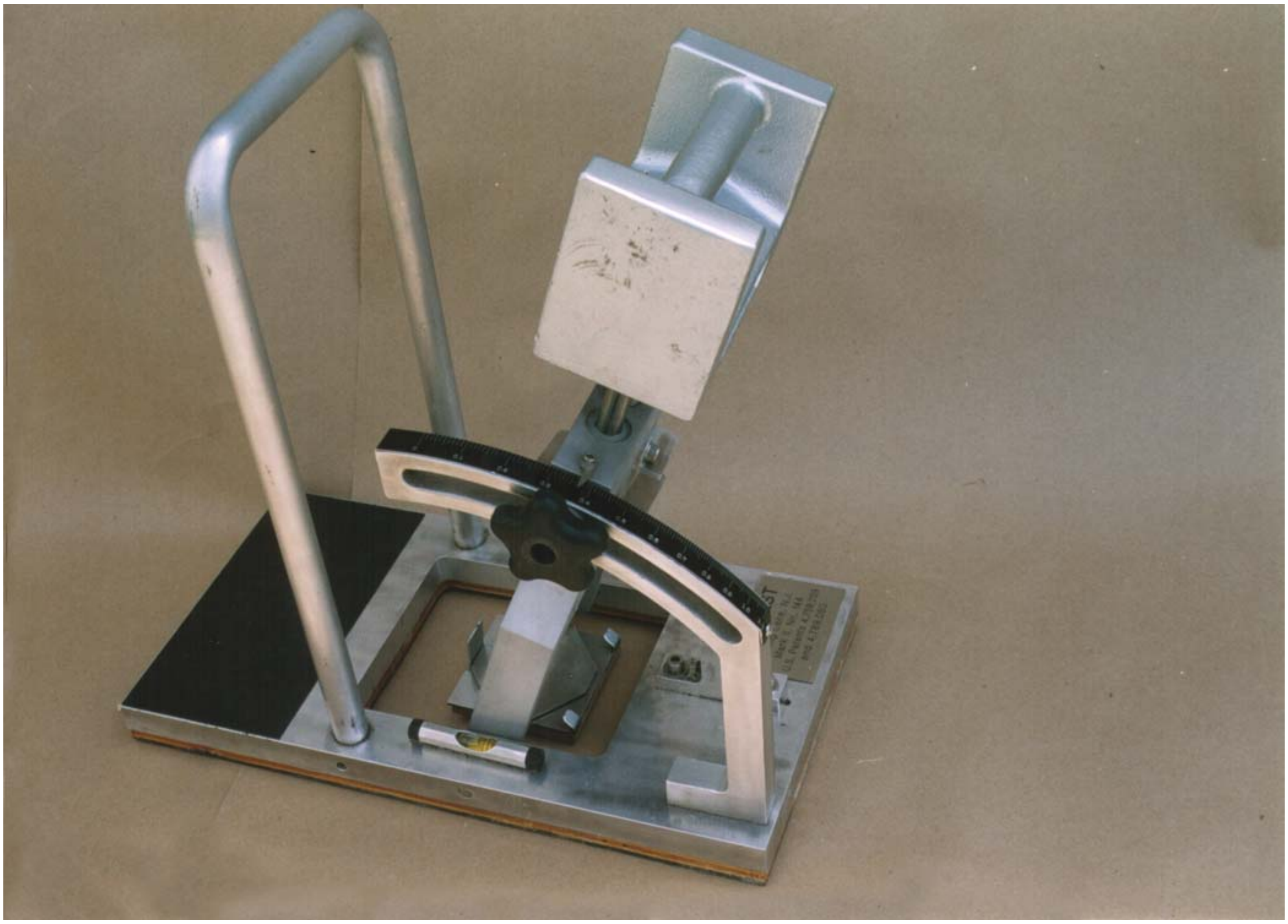

FIG. 1—*Portable Inclinable Articulated Strut Tribometer (PIAST).*

time of testing were 68°F (20°C) with 27% relative humidity. Slip-resistance testing was conducted with the PIAST slip-resistance tester (S/N 144) in accordance with ASTM F1677 (Standard Test Method for Using a Portable Inclinable Articulated Strut Tester).

The testing matrix consists of NTL test feet (non-grooved and varying number of grooves) being tested under wet and dry conditions on two floor samples. All test feet were constructed from the same lot of NTL (Smithers Scientific: Lot # 010402 with an average Specific Gravity of 1.27 ± 0.02 and an average Shore A Hardness of 93–96). The test feet include a non-grooved test foot and eight grooved test feet. The grooved test feet were prepared with 1, 3, 5, 7, 9, 11, 13, and 15 grooves. Each groove was machined 1/8 inch deep (3.17 mm) by 1/16 in. (1.59 mm) wide with a slitting saw. Each high strength steel saw is 4 inches in diameter by 3/64 in. thick and has 40 teeth with concave sides. The grooves are evenly spaced across the width of the test foot. Two test surfaces are used: polished granite and vinyl com position tile.

First, dry testing was conducted on each surface. For the wet testing, the testing surface was wetted by spraying tap water until a film approximately the size of the test foot was achieved. This method resulted in a water film approximately 1–2 mm in height, which was maintained throughout the testing. The order in which the test feet were used was randomized. Six replications of each test matrix condition were conducted. Only the trials that resulted in "full slip" rather than a "partial slip" were recorded. Full slips were defined as per ASTM 1677: when the test foot's forward motion is stopped by the tribometer frame. The last non-slip reading prior to the actual slip was recorded as the slip-resistance value for that trial. This value reflects a static coefficient of friction. The flooring surfaces were cleaned with alcohol both initially and then after each test foot change.

For dry testing, each test foot was sanded prior to its first use and again after each recorded slip. For wet testing, each test foot was sanded once prior to the start of the test, since previous research has shown that sanding under wet conditions does not significantly influence slip resistance (4). Sanding protocol involved sanding the test foot with 400-grit silicon sandpaper four times across the width of the sandpaper in the same direction and then four times in the opposite direction. All sanding was done in a direction that was transverse to the grooves. The investigators took care to keep the sanding pressure equal throughout the testing. After sanding, the test feet were cleaned with a nylon brush to remove any particles. The sanding and brushing procedures were accomplished away from the test surfaces to prevent any contamination.

Results

The results of the present study show that slip resistance depends on floor type and on whether the floor is dry or wet. They also show that slip resistance increases with groove count under all conditions tested. These differences are, however, slight under dry conditions. Data were analyzed with a multiple correlation analysis. Significance was set at 0.05.

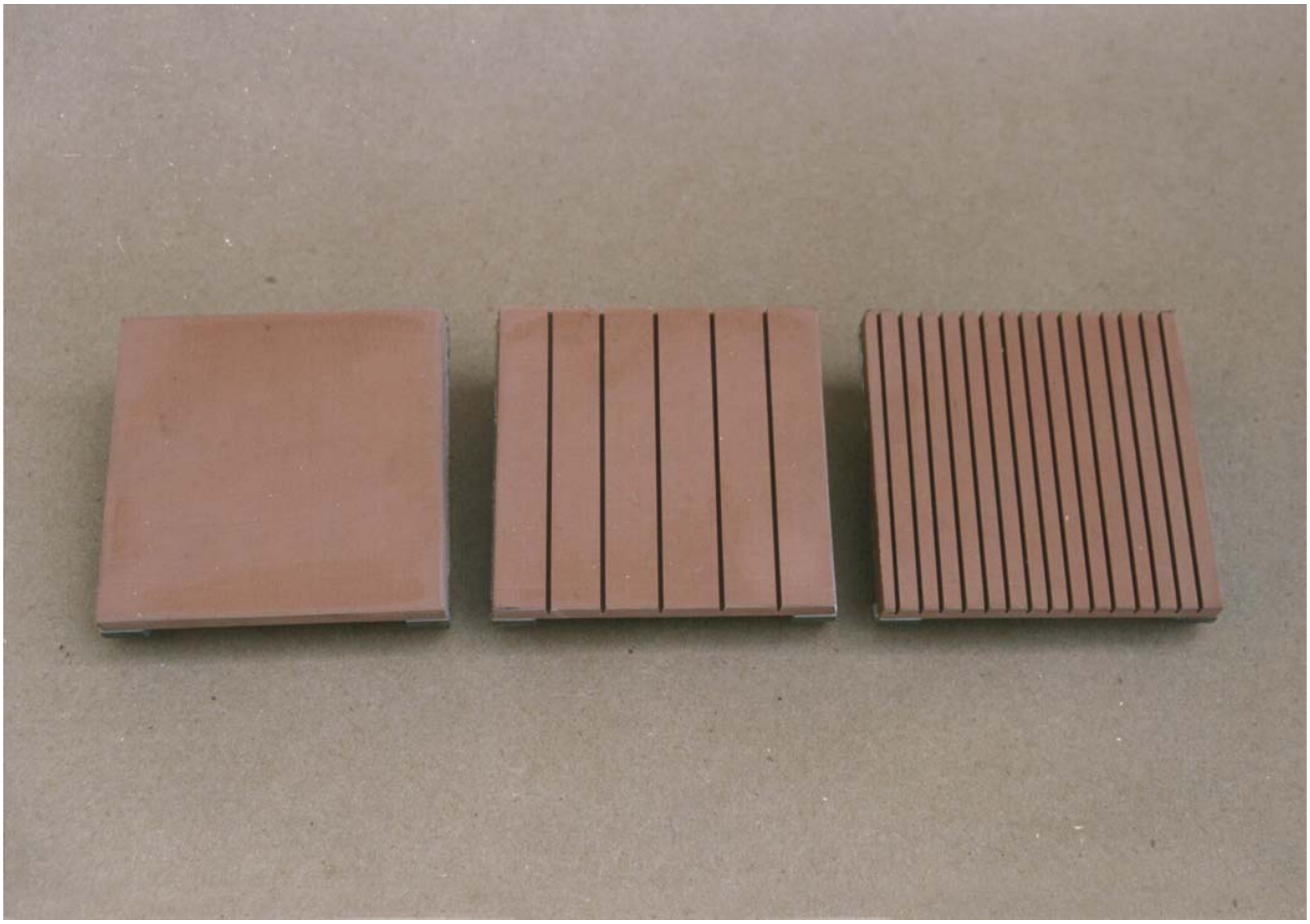

FIG. 2—*NTL Test Feet (from left to right, non-grooved, 5-grooved and 15-grooved).*

Slip resistance values are much higher for the dry condition than the wet condition. For dry granite, the slip-resistance values range from 0.53 for the non-grooved test foot to 0.61 for the 7-grooved test foot, excluding the 13-grooved test foot, which shows a slip resistance of 0.79. This value appears to be an anomaly in the data and is discussed in more detail later in the paper. For dry vinyl composition tile, the slip-resistance values range from 0.60 for the non-grooved test foot to 0.74 for the 15-grooved test foot. For wet granite, the slip-resistance values range from 0.01 for the non-grooved test foot to 0.26 for the 15-grooved test foot. For wet vinyl composition tile, the slip-resistance values range from 0.04 for the non-grooved test foot to 0.32 for the 15-grooved test foot.

The results are graphically shown in Fig. 3 with each data point representing the average of the six trials. This graph displays several notable trends. First, as would be expected, there is a marked difference between the wet and dry conditions. A second expected result is the strong positive correlation between groove count and slip resistance under the wet conditions ($r^2 = .92$ and .90 for the VCT and Granite, respectively). An interesting result is the moderate positive correlation between groove count and slip resistance under the dry conditions ($r^2 = .58$ and .30 for the VCT and Granite, respectively). The data also shows that the VCT consistently provided higher slip resistance values. Interestingly, the comparison between the VCT and granite demonstrates virtually perfect parallel regression lines. The slopes from the regression analysis are identical to within 0.01.

TABLE 1—*Mean and standard deviations.*

Number Grooves	Dry		Wet	
	Granite	VCT	Granite	VCT
0	0.53 (0.04)	0.60 (0.08)	0.01 (0.00)	0.04 (0.01)
1	0.54 (0.06)	0.61 (0.07)	0.01 (0.00)	0.05 (0.01)
3	0.58 (0.05)	0.60 (0.06)	0.03 (0.03)	0.10 (0.02)
5	0.56 (0.08)	0.64 (0.03)	0.07 (0.01)	0.14 (0.01)
7	0.61 (0.02)	0.71 (0.05)	0.08 (0.02)	0.16 (0.06)
9	0.60 (0.04)	0.67 (0.04)	0.10 (0.03)	0.20 (0.04)
11	0.56 (0.03)	0.62 (0.02)	0.24 (0.07)	0.19 (0.02)
13	0.79 (0.06)	0.67 (0.05)	0.20 (0.06)	0.29 (0.05)
15	0.58 (0.02)	0.74 (0.01)	0.26 (0.05)	0.32 (0.01)

The standard deviations from the six trials for each of the testing parameters are shown in Table 1. Interestingly, the data exhibits either a positive or negative trend depending on the environmental conditions. Under the wet condition, there is a trend for increased variability with an increasing groove count whereas the dry condition shows an increase of variability with decreasing groove count.

Discussion

Comparison of the Medoff et al. results (3) with the present study are shown in Table 2. As previously mentioned, the results for the present study show an increase of 0.05 and 0.14 for the granite

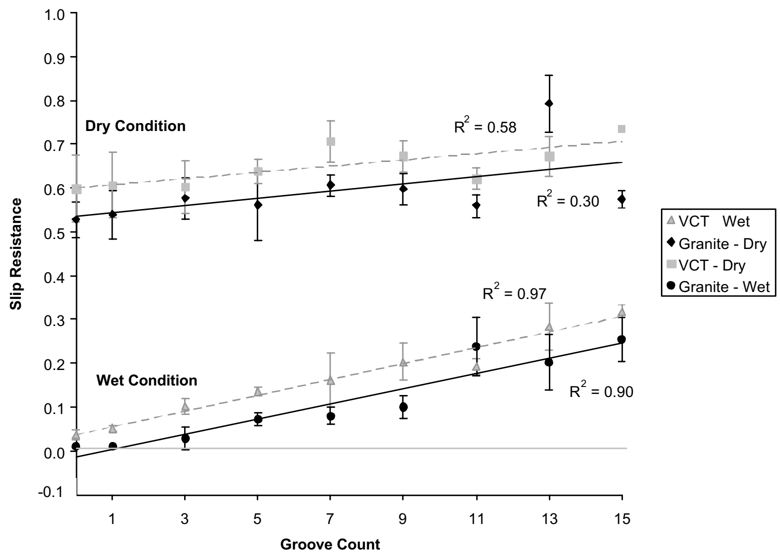

FIG. 3—*Slip resistance.*

TABLE 2—*Slip resistance comparison between smooth and 15-grooved NTL.*

Medoff et al. [3]	Smooth	15-groove	Delta
Quarry Tile			
Dry	0.91	0.93	0.02
Wet	0.14	0.87	0.73
Glazed tile			
Dry	1.08	0.77	−0.31
Wet	0.01	0.32	0.31
Present study			
Polished granite			
Dry	0.53	0.58	0.05
Wet	0.01	0.26	0.25
Vinyl composition tile			
Dry	0.60	0.74	0.14
Wet	0.04	0.32	0.28

and VCT, respectively for the 15-grooved NTL. Medoff, et al. show an increase of 0.02 for the quarry tile but a decrease of 0.31 for glazed tile (15-grooved NTL). This latter result is rather surprising because it is of the same magnitude as the increases seen under wet testing and its directionality is opposite to their results for quarry tile as well as the results in the present study. Medoff, et al. do not offer any explanation for this result.

Although the present results indicate an increase of slip resistance under dry conditions with increasing groove count, the authors do not consider these variations to be of practical significance within the context of walkway safety for two reasons. First, the variations are relatively small. Secondly, all the measured slip resistance values exceed 0.5, the level widely thought to provide an adequate margin of safety for normal walking for most pedestrians under most conditions (5). From a practical standpoint, this means the classification of these floor surfaces as "slip resistant" by the 0.5 minimum value criterion would not be altered by groove count.

According to the Amontons-Coulomb friction theory, which holds that the coefficient of friction is independent of contact pressure, one would not expect the slip resistance to vary with groove count. However, Marpet and Brungraber, who studied the effects of contact pressure and slip resistance, suggest that, while this pressure independence tends to hold reasonably well for non-resilient materials, it may not hold for the resilient materials involved in walkway friction measurements (6). Their results show only slight effects and interaction of the two test surfaces; unglazed quarry tile and glazed tile. Instead of introducing grooves into their NTL test foot, they vary the contact pressure by reducing the width of a 3-in. square NLT to avoid the possibility of "anomalous mechanical interlock." While the Marpet and Brungraber study and the present study are not directly comparable, their study may offer insight into the results of the present study. Although neither contact area nor contact pressure is quantified in the present study, it would be reasonable to conclude that there is a direct positive correlation with contact pressure and slip resistance. Furthermore, given that contact pressure may account for only slight changes in slip resistance, it would be reasonable to speculate that the observed changes in slip resistance with increasing groove count under the dry conditions are due to resiliency changes of the NTL structure introduced by the grooves. In essence, the increasingly thinner beams may exhibit greater deformation under loading, giving rise to an increase in mechanical interlocking.

The results for the wet condition show marked increases in slip resistance with increasing groove count. It would be logical to deduce that the non-grooved NTL hydroplanes on a water film that remains between the NTL and the floor surface because the water cannot be readily squeezed out. In this case, the load is being supported by the water film, which provides relatively small resistance to shearing forces (7). In contrast, it appears that grooves effectively channel the water film out from between the NTL and the flooring surface, thereby reducing hydroplaning. This effect is analogous to the treads of vehicle tires increasing traction on wet driving surfaces. Subsequent high-speed video analysis apart from the present study clearly shows water being channeled out from between the NTL and flooring surface, thus supporting the notion of the grooved NTLs minimizing hydroplaning.

While the changes of slip resistance under the dry condition are not of practical significance, the results for the wet condition have significant implications in the context of walkway safety assessment, because groove count shows considerable influence on slip resistance. Safety practitioners often use several benchmarks in accessing the "safety" of a walkway. A slip resistance value of 0.5 is a commonly accepted available slip-resistance value for an adequate margin of safety for most pedestrians for walking on normal, level surfaces. Additionally, it has been found that for normal, level walking, a coefficient of friction around 0.2 is utilized (8). Hence, many practitioners will indicate that 0.3 is a marginally acceptable coefficient of friction and values below 0.2 are indicative of "slippery" surfaces. It is clear from the testing results under the wet condition that the difference between the non-grooved and 15-grooved NTL spans these benchmarks, thus yielding entirely different conclusions regarding the adequacy of the slip resistance in particular scenarios and public safety. One must also keep in mind that that good safety engineering practice for public safety requires that the testing be conservative. Use of the non-grooved NTL test feet still offers valid results in this context since many pedestrians walk with non-treaded shoes or shoes with well worn soles (9).

The wet testing results support the concept of textured shoe soles reducing the chance of a slip-initiated mishap. For example, shoe sole texture has been shown to eliminate hydroplaning, a possible contributor to slipping (6). It is interesting to note that the relatively new ANSI/ASSE A1264.2-2001 Standard for the Provision of Slip Resistance on Walking/Working Surfaces (10) includes references to shoe tread design for its contribution to slip resistance. One must also keep in mind that the ability of the treads and/or grooves to channel away a liquid film is not the only factor related to slip resistance. The draping of the shoe heel and sole about the asperities of the flooring surface and the true contact between the interacting surfaces also influence slip resistance on liquid-contaminated floors (11).

The data range for the dry conditions shows a fairly tight range except for the noted anomalies in the data for the 13-grooved NTL. Additionally, all six measurements that comprise the 13-grooved NTL data point show a shift from the predicted value. The sources of these anomalies are unclear. The present study controlled for factors in testing methodology, including the NTL material. As previously discussed, the NTL test feet were produced from the same Neolite® production lot and machined with relatively tight tolerances. Additionally, visual inspection did not reveal any inconsistencies in the machining of the grooves or the Neolite® material itself that that could account for this anomaly. A possible explanation for this anomaly could be the structural behavior of the particular 13-grooved NTL test foot. Additional investigation to ascertain the underlying mechanism into this observed anomaly is beyond the scope of the present study.

The variability for the individual data points are worth noting. As previously discussed, each data point is the average of six replications. The variation for the wet conditions demonstrates a trend for increasing variability with groove count. A possible explanation could be that the grooves introduce complex fluid flow patterns that ultimately result in greater variability. The authors attempted to maintain a constant fluid film on the test surfaces to minimize any variations due to fluid film thickness and coverage. In contrast, the variability for the dry conditions shows a trend for increased variability with decreasing groove count. The authors did not identify any apparent sources for this variability. A possible source of variability for both the wet and dry conditions is tribometer bounce (the motion that can be experienced during contact between the NTL and the flooring surface). The authors are not aware of published research regarding this subject, but personal experience has shown that bouncing can alter slip resistance readings. Tribometer bounce was minimized by applying an adequate force to the tribometer during testing.

The present study investigats the slip resistance of a limited number of test surfaces across a spectrum of grooved NTL test feet. A logical next step would be to correlate grooved NTL test feet with actual shoes of various materials and tread patterns, including shoes with well-worn soles and non-treaded soles. Other researchers should look to replicate this study and expand the scope of the study by testing additional flooring surfaces, tribometers, dimensional groove parameters and alternative groove configurations, such as grooves oriented perpendicular to the direction of walking. Observational studies using high-speed video analysis could provide insight of NTL's structural behavior and fluid flow patterns.

Conclusions

Based on the results of this study, we conclude the following. The addition of grooves in the NTL test feet influences slip resistance, especially under wet conditions. In both the wet and dry conditions, the observed slip resistance increases with increasing groove count. The differences under dry conditions are, however, relatively small and would not change an evaluation as to whether the tested flooring surface provides adequate slip resistance in the context of walkway safety. In contrast, the observed differences with the grooved NTL under the wet conditions are of sufficient magnitude that they could change such an evaluation.

We also conclude that interpretation of slip resistance results with non-grooved and grooved NTL test feet depends, in part, on the context in which the tests are made. In the area of walkway design for pedestrian safety, non-grooved NTL test feet provide conservative results since they would likely be reflective of shoe soles with little or no treads and thus may provide a reasonable design benchmark for walkway surface selection. (Within this study, the authors are using the term "conservative" to mean measured slip resistance values that are at the low end of the range typically found in actual walkway environments for any given sole/surface interface.) In the context of investigating particular walking scenarios, as in forensic analysis, the traditional use of non-grooved test feet can still be appropriate, since they are likely to be reflective of shoes with little or no treads. The use of grooved test feet offers intriguing possibilities for expanding the application of slip resistance testing, because grooved test feet are likely to be reflective of many pedestrian shoes that have treads. Consequently, grooved NTL test feet may provide more reasonable slip resistance values by which to evaluate a walkway's performance regarding interaction with specific shoe soles during human gait. As previously mentioned, additional research is needed to further establish this relationship.

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References

1. Marpet M. Comparison of walkway-safety tribometers. JOTE 1996; 24(4):245–54.
2. ASTM C 1028–96: Standard test method for determining the static coefficient of friction of ceramic tile and other like surfaces by the horizontal dynamometer pull-meter method, Vol. 15.02. West Conshohocken, PA: ASTM International, 2003.
3. Medoff H, Fleisher DH, DiPilla S. Comparison of slip resistance measurements between two tribometers using smooth and grooved neolite®-test-liner test feet. *Metrology of Pedestrian Locomotion and Slip Resistance*, *ASTM STP 1424*. Marpet MI and Sapienza MA, editors. West Conshohocken, PA: ASTM International, 2002;67–72.
4. Fendly A, Marpet M, Medolf H, Schutter D. Repeatability and reproducibility in walkway-safety tribometry: abrasive-grit size in test-foot preparation. JOTE 1999;27(1):76–7.

5. Miller JM. Slippery vs. slip-resistant work surfaces: the background for a regulatory definition, IOE/CE-83/02, Occupational Health and Safety Administration Contract B9F26034. Ann Arbor, Michigan: University of Michigan, 1993.
6. Marpet M and Brungraber R. The effect of contact pressure and test-foot sliding on slip resistance: experimental results. J Forensic Sci 1996; 4(5):770–5.
7. Bharat Bhushan BK. Gupta Handbook of Tribology—Materials, Coatings, and Surface Treatments, McGraw Hill, Inc.,1991.
8. Redfern M, Cham R, Gielo-Perczak K, Grönqvist R, Hirvonen M, Lanshammar H, et al. Biomechanics of slips. Ergonomics 2001;44(13): 1138–66. [PubMed]
9. Wilson M. Slip resistance characteristics of footwear solings assessed using the SATRA friction tester. JOTE 1996;24(6):377–85.
10. ANSI/ASSE A126.2–2001, Standard for the Provision of Slip Resistance on Walking/Working Surfaces, E5.3, Shoe and Allied Trade Research Association (SATRA) Recommendations, Appendix A, 2001.
11. Chang W, Grönqvist R, Leclercq S, Myung R, Makkonen L, Srandberg L, et al. The role of friction in the measurement of slipperiness, part 1: friction mechanisms and definition of test conditions. Ergonomics 2001;44(13):1217–32. [PubMed]

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