Comments on ASTM F2508 – 13

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ABSTRACT

In 2013 the American Society of Testing and Materials (ASTM) F13 committee on Pedestrian/Walkway Safety and Footwear, adapted a new standard F2508-13 "Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces". The purpose of the standard is to provide a procedure for validation and calibration of tribmeters so that that their readings of the Coefficient of Friction (COF) in wet conditions will be more reliable and consistent. The drive behind for this standard is a well-known problem where there are large deviations between the readings obtained by different tribometers when measuring the COF between the same surfaces under wet conditions. The standard is based on a study in which four different reference surfaces were ranked according to their slipperiness measured by the number of slips detected while subjects were walking across them. A validated tribometwr, according to this standard, is required to correctly rank the slipperiness of reference tiles with statistically significant differentiation between the COF readings. It is should be emphasize that the standard does not dictate any particular COFs' values for these reference surfaces.

The purpose of this paper is to point out some of the difficulties in applying this standard: 1) Different validated tribometers produce different values for the Coefficient of Friction (COF) of the same ranked surface. Or, vice versa, for the same value of the COF different tribometers will rank the surface's slipperiness differently; 2) Reference surfaces are not the same; and 3) The COF of the higher friction surfaces depends on the direction of the test which is not necessarily in the direction that a person slipped during the accident. These issues will present confusion in case of litigation and the test results are subjected to subjective interpretations.

Keywords: Coefficient of friction, Friction Measurements, Slipmeters, Tribometers,

I. INTRODUCTION

Slips and falls accidents are the leading cause of workers' compensation claims and the leading cause of occupational injury for people aged 55 years and older. Compensation & medical costs associated with employee slip/fall accidents is approximately $70 billion annually [1]. A report by The Bureau of Labor Statistics [2] states "Together, falls, slips, or trips accounted for 35 percent of the injuries and illnesses to heavy and tractor-trailer truck drivers in 2014." In [3] it is reported "'falls on the same level is the second highest category of compensable loss and cost $6.7 billion, according to the 2006 Liberty Mutual Workplace Safety Index. Further, the cost for these injuries grew more than 30 percent from 1998 to 2004." There are numerous reports on the subject but one that demonstrate the severity of this problem is given in a report of a study performed by the National Floor Safety Institute (NFSI) that found that more than 3 million food service employees and over 1 million guests are injured annually as a result of restaurant Slips and Falls accidents. These injuries are increasing at a rate of about 10% annually [4].

The slipperiness of a surface depends on many factors including: presence of moisture or contaminants, slope and cross slope, surface texture, wear, surface finish and the Coefficient of Friction (COF) between the sliding surfaces. However, the measurement of COF, which is the dominant factor effecting slipperiness, is commonly used to qualify a walking surface as a safe one.

The COF is defined by the ratio of the shear force that acts tangent to the contact surfaces between two bodies and the normal force between the two bodies. Thus, in order to find out the value of the COF both forces have to be measured while the bodies are impending motion for the Static COF or in motion for Dynamic COF. In case of Slip and Fall accident the static COF is of interest since it represents the maximum available friction. Once slip occurs, the value of the COF assumes its dynamic value which is lower than the static one. Thus, the static COF represents a threshold between slipping and non-slipping conditions.

Although it might be perceived as a very simple measurement process, test results, of the same surface, might be substantially different due to: 1) Inconsistency of COF readings from one operator to another; 2) Inconsistency of COF readings from one tribometer to another; 3) Inconsistency between reference surfaces; 4) Inconsistency with the same reference surface; and 5) Inconsistency in COF reading of the same model tribometers.

To address difficulties in measuring COF, different organizations, such as ASTM and ANSI, developed numerous standards (a partial list is given in Appendix I). In addition, experts and researcher do not agree on a COF value which ensures a safe floor. However, the value of 0.5 is commonly agreed as the threshold between slippery and non-slippery condition. Many codes adapted this value and a good survey can be found in [5].

In 2013 the American Society of Measurements and Materials (ASTM) established a new standard - ASTM 2508 "Standard Practice for validation, calibration, and certification of walkway slip meters using reference surface" [6]. The standard provides the following:

1. Provides a walkway tribometer supplier (and other entities) with procedures and suit of reference surfaces to validate their walkway tribometer.
2. Provides the user of such tribometers with a procedure and suit of reference surfaces to test whether or not his tribometer is calibrated to the manufacturer's specifications.
3. Describes the necessary materials, specification, foot treatment and the cleaning process of the reference surfaces.

The standard is not addressing the issue of the interpretation of the readings obtained by these tribometers and leaves it to the user.

The validation by the supplier consists of a series of 40 tests, in wet conditions, on each reference surface (10 tests for each the four perpendicular direction). These surfaces, provided by ASTM, are Black Granite, VCT (Vinyl Composition Tile), Porcelain and Ceramics which are ranked as Very Slippery, Moderately Slippery, Acceptable Slippery and Not Slippery respectively. The tribometer is considered valid if:

1. It ranks the four reference surfaces slipperiness in the proper order. For this purpose the mean value of the (COF), of each tile, is used.
2. There is significant differentiation between the results obtained for each surface. This is determined by the following:

$$t = \frac{d_m}{SD/\sqrt{N}} \qquad (1)$$

Where d_m is the mean of the differences between of all data point of consecutively ranked surfaces, divided by the number of pairs (40):

$$d_m = \frac{\sum_{1=1}^{40}(A_{j+1} - A_j)}{40} \qquad j = 1,2,3 \qquad (2)$$

where the index j increases from "Very Slippery" to "Not Slippery" etc.

SD is the standard deviation of the differences between all pairs and N is the number of pairs (40)

3. If t is larger than 1.694 than a statistically significance exists between the COFs of the two surfaces. Otherwise, no statistically significance exists between the two surfaces. This statistical treatment assumes that the data in normally distributed which is not necessarily the case.

The user has to check and determine if his tribometer is calibrated by conducting 16 tests on the same reference surfaces. If the means of the COFs that were found falls within the 95% confidence level that was provided by the manufacturer his tribometer is considered to be calibrated.

The standard is based on a research performed at USC [7] on 84 health young human subjects (42 males, 42 females) between the ages of 22 and 38 (mean 25,9 ± 3.8 years). The subjects were walking at the speed of 2.18±0.13 m/s across the above mentioned 4 tiles, in wet conditions, and slip occurrence was detected by cameras. The slipperiness of the tiles was ranked according to the numbers of detected slips (heel or toe) and the coefficient of friction of these tiles was measured by variety of commercial slip meters. The above two criteria were applied to the readings of each tribometer for its validation.

The use of young healthy subjects for this research implies that if a healthy young person is in risk of slipping than an older persons or persons who are not in good health are exposed to higher risk of slipping. Also, walking speed of 2.18 m/s (4.876 mph) is a very high walking speed which requires a very large steps (displacement) increasing the probability of slip [8, 9]. Average walking speed is 2.8 mph (for young people 3.37 mph and for older people 2.65 mph).

II. ANALYSIS OF TESTS' RESULTS PERFORMED IN [7]

Out of the 12 tribometers that were tested in [7] only 4 passed the two criteria mentioned above. The mean values of the COF, for the 4 reference surfaces, measured by these tribometers, are shown in Figure 1.

Similar tests were reported in [10] in which 9 tribometers were tested on 3 different surfaces (HPL, Derlin and Teflon) in dry and wet conditions. These cases were ranked, using three slipperiness categories: Not Slippery, Slippery and Very Slippery, according to the number of slips detected on each surface. Out of the 9 tribometers only 2 passed the criteria specified above. The values of COF obtained by theses two tribometers are shown in Figure 2.

Observing the results shown in Figures 1 and 2, which were obtained by validated tribometers, raises the following concerns:

1) There are large differences in the values of the COF obtained by these tribometers for the surface (see Figures 1 and 2). For example, on a surface ranked as Not Slippery tribometer C reads a COF value of 0.69 while tribometer B reads a value of 0.42. This is a difference of almost 40%.
2) Due to the particular ranking it is difficult to determine the risk in an intermediate reading. For example, a reading of 0.21 by tribometer A ranks the surface between Moderately Slippery and Acceptable Slipper. Thus, the interpretation of the COF's value with regard to the risk of slipping is subjective (see dash line in Figure 1).
3) The dotted line in Figure 1 demonstrates another problem: The user of tribometer A will rank the surface as Moderately Slippery; the user of tribometer B will rank the surface as Acceptable Slippery and the user of tribometer D will rank the surface as Very Slippery. In case of litigation these three different classification of the surface will cause a major confusion.
4) It is interesting to note that for Slippery and Very Slippery conditions (wet or dry conditions), shown in Figure 2, the value of the COF is below 0.5 which is used in many codes as the threshold between slippery and not slippery conditions.

III. ANALYSIS OF TESTS' RESULTS PERFORMED BY TRIBOMETERS' SUPPLIERS

Once the new standard was published, tribomiters' suppliers had to validate their tribometers accordingly. Some suppliers published the results of their validation's tests [11, 12, 13]. The tests' results on dry surfaces, for three tribometers, are shown in Figure 3.

It should be noted that tribometers E, and G did not pass the validation tests performed in [4]. Figure 4 illustrates the difference between the suppliers' tests' results and the ones published in [4]. As shown, there are large, above 60% in one case, differences between the measurements. It should be emphasize that the tests were performed on the same reference surfaces. These discrepancies are not likely due to operator's skill since the test were performed by trained and experienced operators. It is probably due to differences between same model tribometers, differences between the reference surfaces and other factors.

IV. VARIABILITY BETWEEN SLIP METERS OF THE SAME MODEL AND SUPPLIER

A study performed by "Zurich Services" [14] compares the performance (COF readings) of the same model tribometers supplied by two suppliers (A & B), each provided 3 same model devices (will be referred as A-1, A-2, A-3, B-1, B-2 and B-3). The experiments were performed under wet and dry conditions. All the tests' feet were calibrated using a Tile Council of North America TCNA C-1028 calibration tile which was included with each individual tribometer kit. The TCNA C-1028 calibration tile is made of ceramic material and have a matte finish. Each test was repeated 12 times and the mean was used for comparison.

Figure 5 illustrated the deviations in the readings of the COF obtained by each tribometer relative to the mean of all measurement obtained by the same three tribometers on the same surface. The graphs, for dry conditions, indicate that in some cases the deviation value exceeds 10% which might classify the slipperiness of the surface wrong. On wet surfaces, the problem that this standard is addressing, the deviations are larger and in some cases they exceed 50% which has high probability to rank the slipperiness of the surface wrong.

It should be emphasize that the differences between same model same supplier tribometers is being addressed by the new standard since each individual tribometer has to be validated by the supplier and its particular characteristics (mean COF as well as the 95% confidence interval for each reference surface) are provided to the user for the purpose of calibration of his own tribometer. However, such large variations might lead to false classification of actual tested tile.

V. VARIABILITY BETWEEN REFERENCE SURFACES

The standard is based on the assumption that the characteristics of the reference surfaces, being used by the suppliers and the users, are the same within 95% confidence interval. This assumption has not been verified in particular since the tiles are manufactured by a process which has its own variabilities. As results, it is expected to observe variations in the value of COF from one tile to another. Thus, variations between different sets of reference surfaces are expected. The problem becomes an issue where there are differences between the reference surfaces used by the manufacturer and the one being used by the user for calibration of his tribometer.

The following is a court case where an English XL tribometer, validated by the supplier using ASTM F-2508 standard, was used to measure SCOF in wet conditions [15]. The details of the opinion are not of interest here. The expert calibrated his tribometer according to ASTM F-2508 standard using the 4 reference surfaces that were provided by ASTM. His opinion was rejected since the values of the COF he obtained during calibration did not fall within the 95% confidence interval provided by the supplier (see row 1 and 2 in Table 4). After the trial the expert's tribometer was sent back to the supplier for testing. The results of the expert's calibration tests and the ones conducted by the supplier are shown Table 1.

The first row in Table 1 shows the 95% confidence intervals for each reference surface given by the tribometer's supplier. The second row provides the values of the COF measured by the expert during the calibration process using his reference surfaces. **Notice that none of the calibration values fall within the 95% confidence intervals.** The third row shows the results, obtained by the supplier tests, when using the expert's tribometer and the supplier's reference surfaces. **Again, none of these values fall within the 95% confidence intervals provided by the supplier.** Lastly, the supplier measured the COF of the expert's reference surfaces using its own tribometer. The results of these tests are given in the fourth row of Table 4. **In this case only one value (Granite Tile) falls within the interval provided by the supplier.**

The tests' results shown in Table 4 raise two questions:

1. It is expected that measurements (see 2nd and 4th rows) obtained by both tribometers, using the same reference surfaces, will be the same (within the 95% confidence interval). Here, the results are different and three out of four readings, obtained by using the supplier's tribometwr, are not within the 95% confidence interval.
2. It is expected that the measured values of the COF using of the same tribometer and two sets of reference surfaces (see 2nd and 3rd rows) would be the same. In this case none of the COFs' values fall within the 95% confidence interval (1st row).

The only conclusion that will explain the above results is that the COFs is different from one set of reference surfaces to another. This conclusion was arrived to in [15] "the tile-to-tile variations in friction in the same areas of the restaurant were also statistically significant

VI. VARIABILITY WITHIN THE SAME REFERENCE SURFACE

ASTM procedure requires 40 tests on each tile 10 in each direction (North, East, South and West). The validation tests' results provided in [11, 12, 13] include the information including the measured COF values as well as the test' direction. If the tile's surface is uniform it expected that the mean value of the COF will be the same in any direction.

Table 1: Tests' results using the expert's tribometer.

	Granite	Porcelain	Vinyl	Ceramic
95th Percentile Confidence Interval	0.078-0.082	0.132-0.137	0.173-0.180	0.605-0.616
Gill's calibration using her tribometer and tiles	0.0700	0.1013	0.1727	0.8505
Excel's calibration using Gill's tribometer and its own tiles	0.066	0.116	0.165	0.576
Excel's calibration using its own tribometer and Gill's tiles	0.080	0.100	0.149	0.641

To test this hypothesis a one way ANOVA test was performed for each tile where the data for each direction is considered as a sample (see results are shown in Table 2). If the surface passed the test it means that the deviations in the mean values of the COF, in all four directions, are insignificant and all readings belong to the same population. In other words the surface's COF is uniform and undependable of the measurements' direction.

The results in Table 2 indicate that, when tribometers I and II are being used, the high friction tiles, C - Acceptable Slippery or D – Not Slippery, are "failing" the test. The tests performed by tribometer III passed the test because the measurements were performed under wet conditions where COF's values are reduce. This means that the COF property of the failed tiles is not consistent

Table 2: One way ANOVA results
(**$F_{critical}$** = 2.86626 for for all cases)

Tribometer	Tile	*F*	*P-value*	Criteria
I	A	0.77665	0.51473	PASS
	B	0.642857	0.59249	PASS
	C	5.92053	0.00216	FAIL
	D	2.535354	0.07210	FAIL
II	A	0.545455	0.65437	PASS
	B	0.861592	0.46984	PASS
	C	0.861592	0.46984	PASS
	D	3.950367	0.01558	FAIL
III	A	0.17321	0.91381	PASS
	B	3.41658	0.02747	PASS
	C	26.91388	2.61E-0	PASS
	D	6.060302	0.00189	PASS

.In order to determine if the test direction has any effect on the value of the COF, the same data was arrange in pairs of opposite testing directions (e.g. North – South). Each pair was tested as follows:

1. First, f-Test was performed to determine if the variances of each pair are the same.
2. According to the f-Test results, t-Test, either for pairs of the same variance or pairs with different variance, was performed in order to determine if the two samples belong to the same population (in other words if their means are the same within 95% confidence interval). The results of these tests are given in Table 3.

The results in Table 3 indicate that all high friction surfaces (C and D) have one particular direction where the value of the COF is being effected by the test direction. This is a clear indication that the manufacturing process affecting the surface in such a way that it is "rough" in one direction and "rougher" in the opposing one.

A series of tests, in which the COF of a TCNA standard tile was measured 10 times in 8 different directions in increments of 45º (North-South, North East- South West etc.), was conducted according to ASTM C1028 standard[1]. The tests were conducted in dry conditions and the results are given in Table 4.

A one way ANOVA test, on the 8 samples, revealed that there is no significant difference between the means indicating that all 8 samples belong to the same population ($F = 2.010117$, $P_{Value} = 0.065407$, $F_{critical} = 2.139656$). However, t-Test of pairs of samples of opposite directions show that in one particular case, North-South, there is significant difference between the means (see t-Test results in Table 5) indicating that there is a difference in the COF values when testing in opposing directions). Worthwhile to note that this direction was parallel to the edge of the tile, indicating that the manufacturing process might affect the surface.

VII. CONCLUSIONS

The new standard for validation of tribometers assumes that the reference surfaces, used by the suppliers and the users, have the same (within 95% confidence level) COF. This assumption has to be checked out in light of the results shown above.

Tribometers, which were validated by the standard, provide different COF, in some cases with large deviation, for the same reference surfaces. Thus, either the reference surfaces are not the same or the measurements are incorrect. This differences present a major issue when it comes to litigation since two validated tribometer might indicate different level of slipperiness.

Also, most safety and building codes specify a minimum value for the COF in order to certify a walking surface, e.g. 0.5, the test result which will identify the surface as "Not Slippery", might have a COF smaller than the required one by the codes. Also, a COF reading that fall between two slipperiness ranking, e.g. between "Moderate Slipperiness and "Acceptable Slipperiness" is open for subjective interpretation.

Deviations in COF within the same tile, measured in opposite directions, is another issue that has to be address since in cases of

[1] ASTM C-1028 was withdrawn in 2014. However, the test is still valid since the reason for withdrawal is not due to technical deficiencies: "**This standard is being withdrawn without replacement due to its limited use by industry".**

Slip and Fall a person might slip in the direction of the low COF while the measurements for validation were taken in the opposite direction.

All this issues can be solved if a reference surface can be produced with very high repeatability resulting the same COF. Thus, it will be expected that all tribometers will measure the same value COF, eliminated the confusion discussed above.

Table 3: f-Test and t-Test results.
(P – Pass the test, F – Failed the test)
(P for f-Test means variances are the same within 95% confidence interval)
(P for t-Test means averages are the same within 95% confidence interval)
($F_{Critical}$(1 tail)=3.178 and $T_{Critical}$*(2 tails)*=2.1 for all cases)

Tribo-meter	Tile	Dire-ction	*F*	*Crit-eria*	T_{stat}	Crit-eria
I	A	N-S	1.35	P	1.386	P
		E-W	1.81	P	0	P
	B	N-S	1.98	P	0	P
		E-W	1	P	1.325	P
	C	N-S	2.75	P	3.113	**F**
		E-W	1.24	P	0.547	P
	D	N-S	1.29	P	0	P
		E-W	1.14	P	2.750	**F**
II	A	N-S	1.19	P	1.394	P
		E-W	2.44	P	0	P
	B	N-S	1.33	P	1.463	P
		E-W	1.23	P	0.884	P
	C	N-S	1.8	P	3.515	**F**
		E-W	1.6	P	0	P
	D	N-S	1.11	P	0	P
		E-W	1.02	P	3.398	**F**
III	A	N-S	1.31	P	0.144	P
		E-W	2.01	P	0.610	P
	B	N-S	9.85	**F**	1.279	P
		E-W	1.20	P	2.368	**F**
	C	N-S	2.11	P	8.504	**F**
		E-W	1.36	P	1.523	P
	D	N-S	15.6	**F**	0.979	P
		E-W	1.95	P	2.286	**F**

Table 4: COF values obtained by the 8-directions tests.

	Direction							
Test	N	S	E	W	NE	SE	SW	NW
1	0.412	0.417	0.441	0.446	0.451	0.475	0.422	0.422
2	0.470	0.417	0.436	0.451	0.523	0.456	0.427	0.489
3	0.484	0.412	0.412	0.417	0.508	0.436	0.508	0.480
4	0.417	0.412	0.393	0.408	0.432	0.403	0.547	0.508
5	0.446	0.398	0.422	0.451	0.393	0.393	0.432	0.508
6	0.446	0.388	0.384	0.398	0.427	0.384	0.384	0.432
7	0.451	0.393	0.398	0.412	0.480	0.432	0.384	0.441
8	0.451	0.441	0.432	0.427	0.499	0.542	0.393	0.441
9	0.412	0.432	0.456	0.436	0.465	0.528	0.369	0.374
10	0.441	0.422	0.465	0.412	0.451	0.499	0.451	0.417
Mean	0.443	0.413	0.424	0.426	0.463	0.455	0.432	0.451
Variance	0.000568	0.000275	0.000732	0.000367	0.001627	0.003071	0.003287	0.001924

Table 5: t-Test results.

	Direction			
	N-S	E-W	NE-SW	SE-NW
F	2.066	1.994	1.890	1.110
$F_{Critical}$	3.178	3.178	3.178	3.178
T_{Stat}	**3.237**	0.182	1.467	0.359
$T_{Critical}$	2.100	2.100	2.100	2.100

VIII. REFERENCES

[1] National Floor Safety Institute, https://nfsi.org/

[2] BLS News Letter USDL 15-2205, November 19, 2015

[3] Liberty Mutual Research Institute for Safety, Vol. 10, No. 3,

[4] Slips and Falls Study: Objective Auditing Techniques to Control Slips and Falls in Restaurants, CNA June 2007. Autumn 2007

[5] Steven Di Pilla, Slip and Fall Prevention – A practical Handbook, CRC Press, 2nd Edition, ISBN-13:978-1420082340, 2010.

[6] ASTM 2508-13 "Standard Practice for validation, calibration, and certification of walkway slip meters using reference surfaces."

[7] C.M. Powers, et. al. "Validation of Walkway Slip meters: Establishing a Reference Standard", J. of Forensic Sciences, Vol. 55, No. 2, March 2010.

[8] Yakeshi Yamaguchi, et. al., "Effect of Step Length and Walking Speed on Traction Coefficient and Slip between Shoe Sole and Walkway", Tribology Online, vol. 3 no. 2, 2008.

[9] Rachel A. Brady, et. al, " Foot Displacement but not velocity predicts the outcome of a slip induced in young subjects while walking", J. of Biomechanics, vol. 33, 2000.

[10] C.M. Powers, et. al. "Assessment of Walkway Slip meter Reading in Evaluating Slip Resistance: A Gait-Based Approach", J. of Forensic Sciences, Vol. 52, No. 2, March 2007.

[11] Report of ASTM F2508 validation of the ENGLISH XL VIT Base-Model variable incidence/articulated strut slip meter with standard XL VIT non-treaded test foot and standardized test foot preparation device **http://www.excelslip meters.com/uploads/download/XL%20VIT%20Base-Model%20F2508%20Std%20Foot%20Validation%20Report.pdf** http://www.excelslip meters.com/uploads/download/XL%20VIT%20with%20Sequencer%20F2508%20Std%20Foot%20Validation%20Report.pdf

[12] Slip meter Certification (Mark IIIB) http://www.slip-test.com/Slip-Test_MarkIIIB_F2508_Certification.pdf

[13] Copy of ASTM F2508-11 RESULTS DATA COLLECTION TABLE. DATE: SEPT. 6-7, 2011. METHOD: WET DCOF/SBR*/8 INCH. TEMP: 75.3 F. RH: 29%. TILE A. TILE B. TILE C. TILE D. http://s159433513.onlinehome.us/ASTM%20F2508%20Results%20BOT-3000.pdf

[14] Zurich "A Comparison of two slip meters", Risktopic 4-3.010 October 2012

[15] Kill v. City of Seattle http://www.zurichservices.com/ZSC/REEL.nsf/e7d01e983421df7fc125710e00503352/940489e7eecfcfabc1257a910061185e!OpenDocument&ExpandSection=1

APPENDIX I – LIST OF STANDARDS

ASTM Standards

1. F609-05(2013)- “Standard Test Method for Using a Horizontal Pull Slipmeter (HPS)”
2. F462 - 79(2007) - “Standard Consumer Safety Specification for Slip-Resistant Bathing Facilities”
3. F695 - 01(2009) - “Standard Practice for Ranking of Test Data Obtained for Measurement of Slip Resistance of Footwear Sole, Heel, and Related Materials”
4. F1240 - 01(2009)- “Standard Guide for Ranking Footwear Bottom Materials on Contaminated Walkway Surfaces According to Slip Resistance Test Results”
5. F1637 - 13 - “Standard Practice for Safe Walking Surfaces“
6. F1646 – 13 - “Standard Terminology Relating to Safety and Traction for Footwear“
7. F1694 - 14 - “Standard Guide for Composing Walkway Surface Investigation, Evaluation and Incident Report Forms for Slips, Stumbles, Trips, and Falls“
8. D2047 – 11 - “Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine (lab use) “
9. F2048-00(2009) - “Standard Practice for Reporting Slip Resistance Test Results“
10. F2913 - “ Standard Test Method for Measuring the COF for Evaluation of Slip Performance of Footwear and Test Surface/Flooring Using a Whole Shoe Tester“
11. D5859 - “Standard Test Method for Determining the Traction of Footwear on Painted Surfaces Using the Variable Incident Tester (Withdrawn 2005) “
12. F2508-13 - “Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces“
13. E303-93(2013) - “ Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester“

ANSI standards

1. A137.1 - “Tile Slip Test“
2. A1264.1 - “Safety Requirements for Workplace Walking/Working Surfaces and their Access; Workplace, Floor, Wall and Roof Openings; Stairs and Guardrails System“
3. A1264.2 - “Standard for the Provision of Slip Resistance on Walking/Working Surfaces“
4. A1264.2 - “Provision of Slip Resistance on Walking/Working Surfaces“
5. B101.1 - “Test Method for Measuring Wet SCOF of Common Hard-Surface Floor Materials“
6. B101.3 - “Test Method for Measuring Wet DCOF of Common Hard-Surface Floor Materials“

ASTM withdrawn Standards

1. F489-96e1 - “Standard Test Method for Using a James Machine (Withdrawn 2005) “
2. F1677-05 - “Standard Test Method for Using a Portable Inclineable Articulated Strut Slip Tester (PIAST) (Withdrawn 2006) “
3. F1678-96 - “Standard Test Method for Using a Portable Articulated Strut Slip Tester (PAST) (Withdrawn 2005) “
4. F1679-04e1 - “Standard Test Method for Using a Variable Incidence Tribometer (VIT) (Withdrawn 2006) “
5. D5859-96e1 - “Standard Test Method for Determining the Traction of Footwear on Painted Surfaces Using the Variable Incidence Tester (Withdrawn 2005) “
6. C1028-07e1 -“ Standard Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method (Withdrawn 2014) “
7. F802-83(2003) – “Standard Guide for Selection of Certain Walkway Surfaces When Considering Footwear Traction (Withdrawn 2012) “

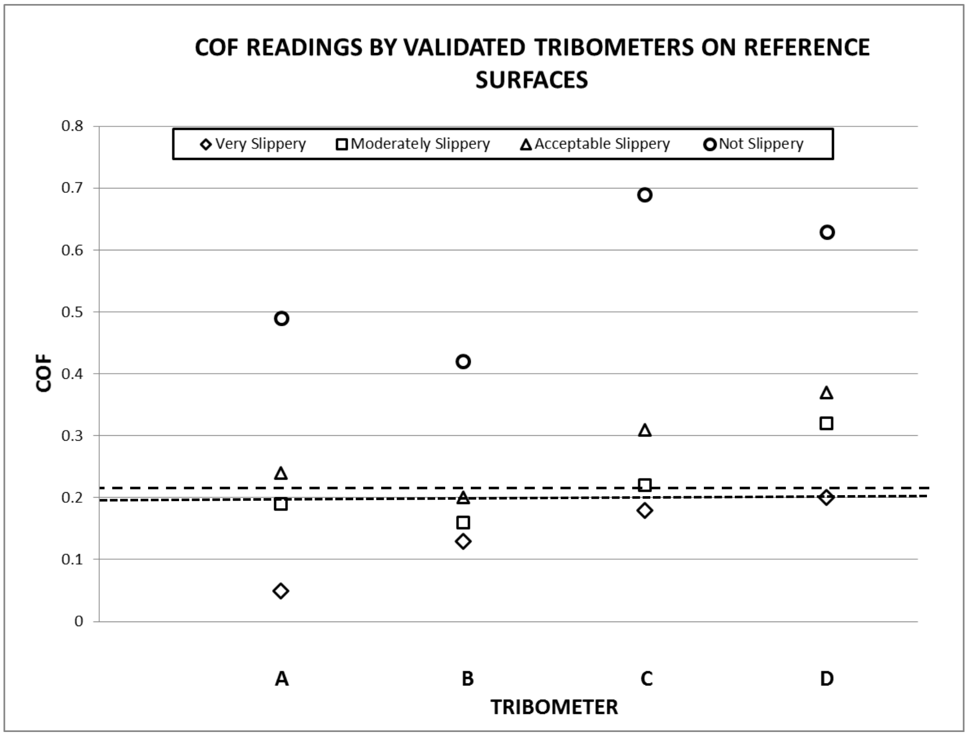

Figure 1: COF measurements of the reference surfaces by the 4 validated tribometers.

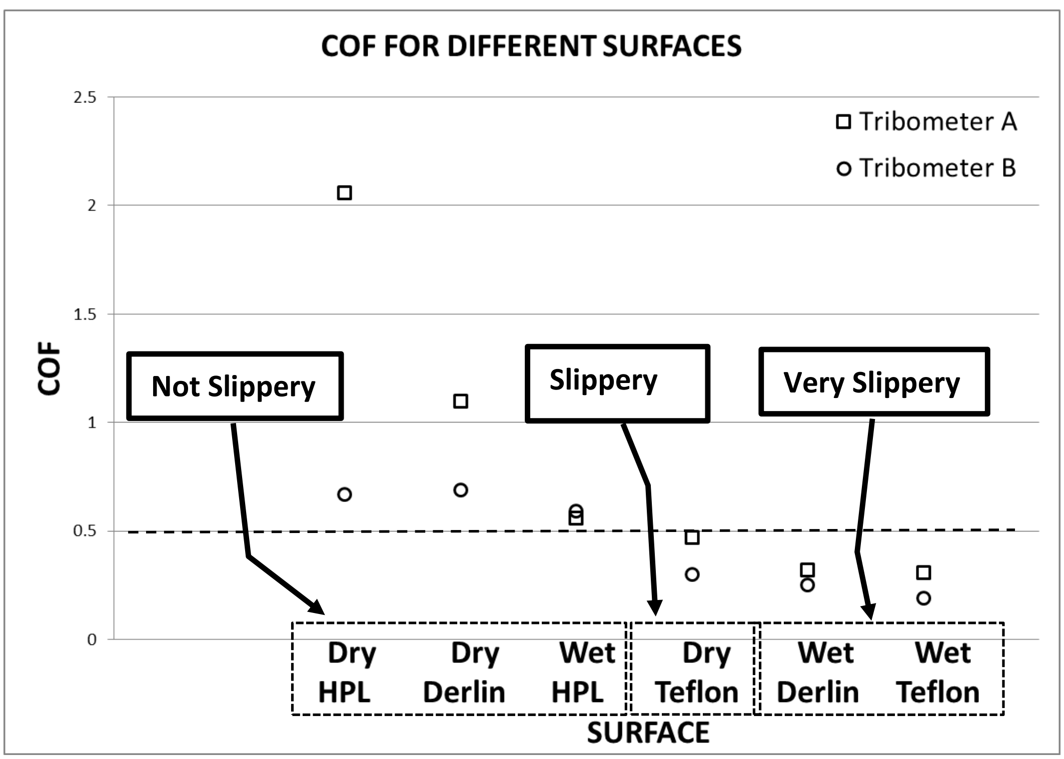

Figure 2: COF measurements of the reference surfaces by the 2 validated tribometers.

Figure 3: Tests' results performed by the suppliers in order to validate their tribometers.

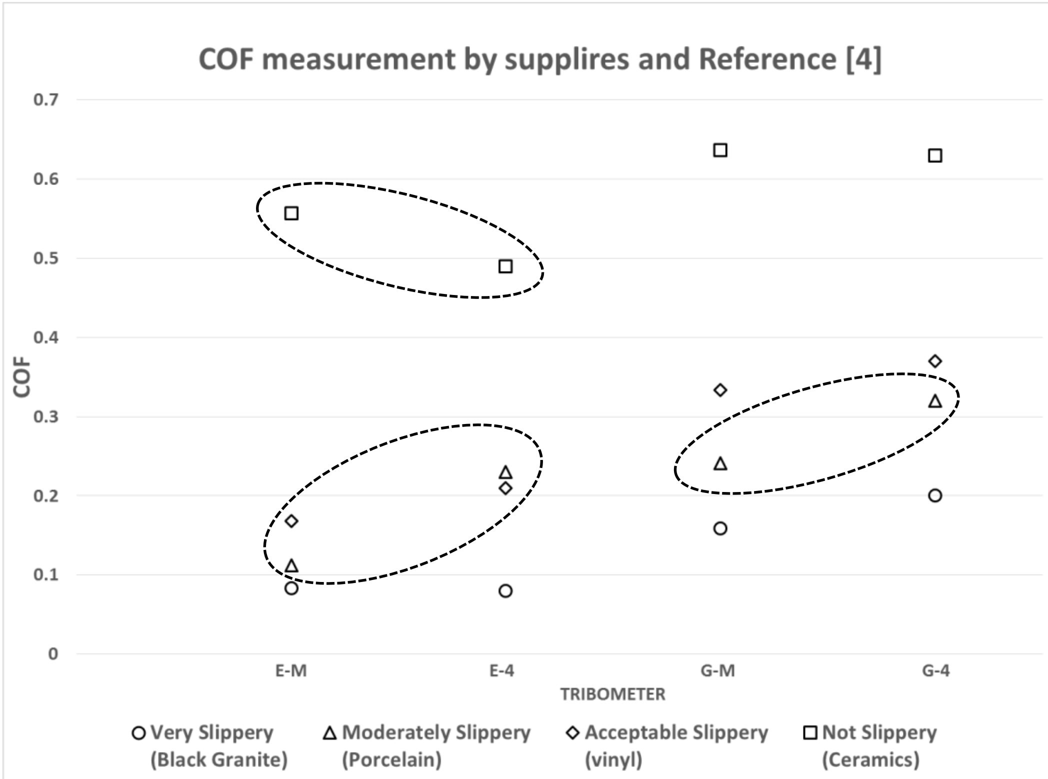

Figure 4: Manufacturers' tests results compared to the results in [4].

(E-M – Tribometer E - supplier's results
E-4 - Tribometer E - Ref. 4 results
G-M – Tribometer G - supplier's results
G-4 - Tribometer G - Ref. 4 results)

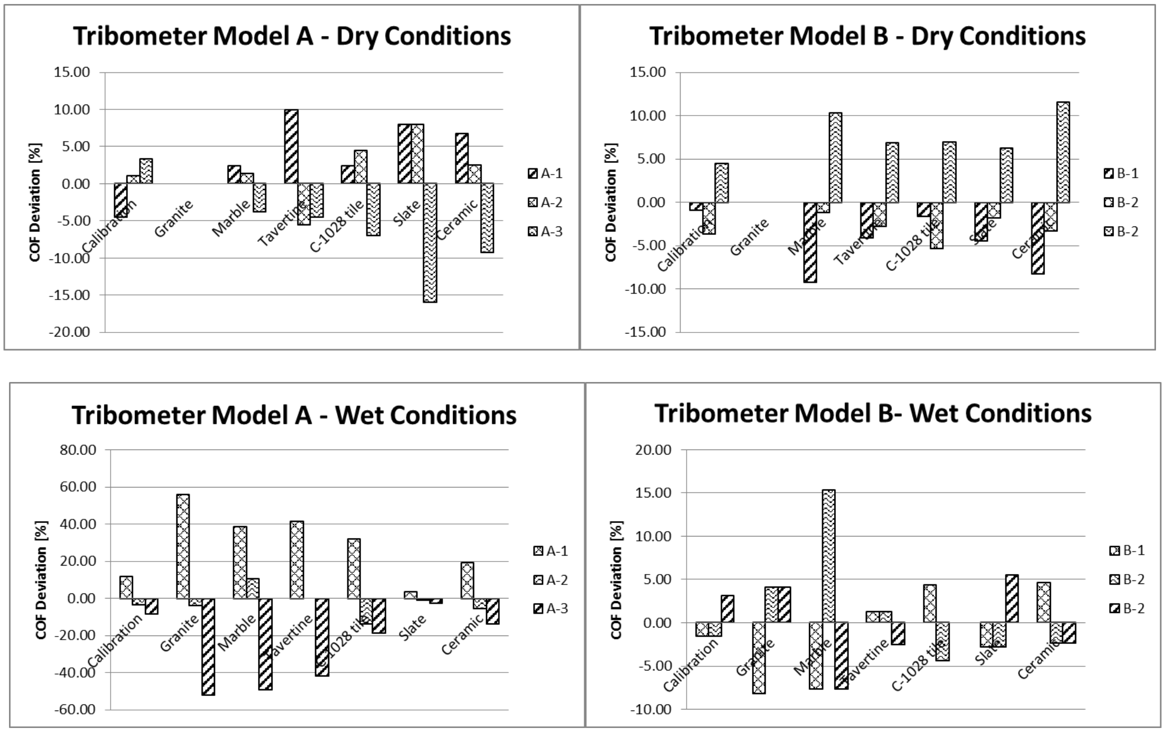

Figure 5: Deviation of the tribometers reading relative to the mean value of COF obtain by the total readings of the three tribometers of the same model.