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The Changing World of Slip-and-Fall Analysis

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Introduction

Pedestrian fall incidents are frequently alleged to be caused by a "slippery" walkway surface. Building codes, safety codes, and accessibility regulations require adequate walkway "slip resistance" without specifying how this is to be confirmed. Demonstrating that a walkway surface provides sufficient (or insufficient) traction is a complex task – requiring expertise and (where appropriate) the use of a *tribometer* for traction measurement. The past five to ten years have seen major advances in the scientific foundations for tribometry, through correlation of tribometer measurements to actual human slip experiences – and this is slowly advancing the "standard of care" for slip-and-fall analyses. The nuances of these scientific foundations are not trivial, however, and the topic has been challenging to understand for both practitioners and laypersons. There have been recent efforts by various standards developers to make pedestrian slip information more useful; the technical robustness of these different efforts varies. It remains to be seen how court decisions will view these various advances, as there are few published court decisions that involve the recent methodologies.

It is important to note that pedestrian slip-and-fall incidents may involve both *intrinsic* elements related to the pedestrian (medical conditions, medications, activities, attentiveness, etc.) as well as *extrinsic* elements related to the walkway environment (traction, contaminants, illumination, distractions, etc.).

Slip Events and the Shoe-Walkway Interaction

Types of Slip Events

There are two main types of pedestrian slip events that are routinely studied:

- Heel slip: This is the most common cause of a slip-related fall. At the end of the swing phase of the stride, as the leading heel contacts the walkway, the heel slides forward. The momentum of the pedestrian exacerbates the slip, and the leading leg is unable to support its share of the body weight
- Toe slip: A toe slip occurs when the trailing foot slips at push off. A toe slip rarely results in a fall, since most body weight has already have been shifted to the leading leg.

Friction and Measurement

Friction is the force resisting the relative motion of adjacent contacting materials. The most familiar quantifier regarding friction (and traction) is the Coefficient Of Friction or COF. This is a force ratio that can be expressed visually as shown in Figure 1.

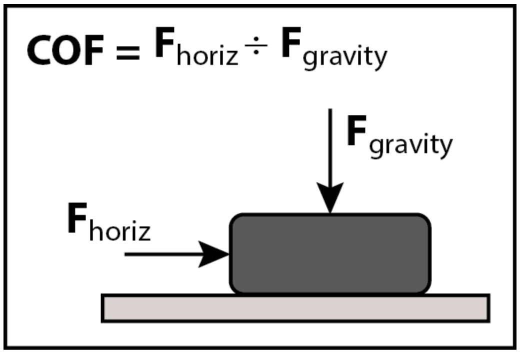

Figure 1 – Coefficient Of Friction (COF)

In the analysis of pedestrian safety, a key consideration may be the frictional interaction between the walkway and the footwear (or foot). Contributing physical elements include (from the scientific topic of "tribology") surface roughness, asperities, slope, contours, draping, contact force magnitude, contact velocity and acceleration, hysteresis, damping, tearing, mechanical interlocking, molecular bonding, plastic deformation, wear, and contaminants (Chang 2001a). Selected elements are discussed below:

- Surface roughness: Evaluated at a microscopic scale, roughness is expressed as the average height of walkway surface features. Though traction is related to the surface roughness of both the walkway and the footwear (or foot), the averaging that is necessary for roughness calculations reduces its usefulness – disparate microscopic walkway surface "profiles" may nevertheless have the same roughness value. Chang (2001b) discusses walkway roughness in detail.
- Asperities: Individual features that protrude above the basic "average" surface. High, sharp asperities may protrude above contaminants for a higher degree of mechanical interlocking with the footwear or foot. The height, sharpness, and distribution of asperities may vary widely across a walkway surface, particularly with broom-finished concrete, natural slate, and some textured ceramic tiles. Hard-surface walkways without significant roughness or asperities, such as polished marble or terrazzo, rely more on molecular bonding and less on mechanical interlocking with the footwear or foot.

Friction measurement is an empirical study, meaning there are no formulas that can perfectly predict frictional interaction - friction must be measured. Walkway traction measurements may be obtained through several methods, which include:

- Tribometer testing: A walkway tribometer is a mechanical or electromechanical device used to measure the frictional forces acting at the interaction of a walkway surface and a footwear material surface. There are dozens of tribometer types and models in use around the world.

- Human subject traction demand testing: In this testing, human test subjects walk along a laboratory walkway that includes a *forceplate*. This thick metal plate is mounted flush to the walkway and is supported by electronic force sensors. These measure the vertical, lateral, and longitudinal walking forces applied to it by the human test subjects. Recalling the "force ratio" concept of COF, these force measurements are used to calculate the traction required by that pedestrian. This testing (often referred to as "required COF" or RCOF) typically does not involve the pedestrian slipping – adequate traction is provided on the force plate surface.
- Human subject slip testing: In this testing, human test subjects walk along a slippery walkway. In level walkway slip testing, a forceplate is often used to evaluate applied walkway forces at the point of slipping. Ramped walkway slip testing is also done, in which a human test subject traverses a slippery ramp surface while the ramp angle is increased up to the point of slip – and the friction measurement is derived from the ramp angle.

<u>Traction Testing Terms</u>

Getting back to the familiar term Coefficient Of Friction or COF, there are many different "types" of COF that are referred to in pedestrian walkway analysis:

- Static (SCOF): The COF calculated when the object is stationary but at the point of incipient slipping.
- Dynamic (DCOF): The COF calculated when the object is sliding along the surface. The maximum value of DCOF is typically at a steady velocity where the moving object is almost stopping.
- Transitional (TCOF): The COF calculated at the transition from static friction to steady-state dynamic friction resulting from simultaneous vertical & horizontal contact force application.
- Required (RCOF): The COF calculated from measured walkway forces applied by a pedestrian. Also called Utilized Coefficient Of Friction (UCOF).
- Available (ACOF): The COF calculated from tribometer testing of the frictional properties inherent in a walkway surface.

The textbook definition of COF discusses that it is evaluated for two adjacent surfaces; however, walkway traction often involves contaminants, which introduce additional "surfaces". A more relevant term for pedestrian walkway traction is "slip resistance". This term is (in practice) often used interchangeably with COF, though its definition clearly goes beyond that of COF:

- Slip resistance: "The relative force that resists the tendency of the shoe or foot to slide along the walkway surface. Slip resistance is related to a combination of factors including the walkway surface, the footwear bottom, and the presence of foreign materials between them" (ASTM F1646).

Laws, Standards, and Requirements for Walkway Traction

<u>Laws and Standards</u>

Three main enforceable codes/regulations require that walkways be "slip resistant", though they do not specify a means for determining this:

- National Fire Protection Association (NFPA) 101 *Life Safety Code.*

- Americans with Disabilities Act (ADA) *Accessibility Guidelines for Buildings and Facilities*: note that prior to 2004 the ADA *recommended* a COF of 0.6 for level surfaces and 0.8 for ramps. These values are widely misquoted as being *current requirements*, though they are neither current nor are they requirements. Further, these values were based on research conducted using a tribometer testing configuration later found to be improper – the soft silicone rubber testfoot used on the tribometer was intended to simulate barefoot pedestrians, not pedestrians in footwear.
- International Code Commission (ICC) *International Building Code*: This standard adopts ANSI/ICC A117.1 *Accessible and Usable Buildings and Facilities.* Both documents require walkways to be slip resistant.

Additional voluntary (non-enforceable) consensus standards that require or recommend that walkway surfaces have a certain amount of traction include:

- American National Standards Institute (ANSI) / American Society of Safety Engineers (ASSE) A1264.2 *Provision of Slip Resistance on Walking/Working Surfaces*: This standard suggests a slip resistance of 0.5, and states that traction testing shall be done using a tribometer that meets ASTM F2508 *Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces*. However, this still does not establish a methodology for verifying a slip resistance of 0.5, as ASTM F2508 is not a traction testing methodology in itself. ASTM F2508 will be discussed later in this paper.
- ASTM F1637 *Standard Practice for Safe Walking Surfaces.*
- ANSI / Tile Council of North America (TCNA) A137.1 *Specification for Ceramic Tile*: This standard covers a variety of factors with ceramic tile, including COF. It specifies a test procedure for DCOF testing and a recommended minimum value for tiles tested using specific tribometers.
- ANSI / National Floor Safety Institute (NFSI) B101.1 *Test Method for Measuring Wet SCOF of Common Hard-Surface Floor Materials*: This standard specifies three different SCOF measurement ranges for different levels of walkway traction. This is only possible due to the standard's reliance on a restricted set of specific tribometer models. As will be discussed, differences in tribometer designs will result in different measurement values on the same surface – precluding the possibility of having one standard "threshold" slip resistance value that works with all tribometers.
- ANSI/NFSI B101.3 *Test Method for Measuring Wet DCOF of Common Hard-Surface Floor Materials*: This standard specifies three different DCOF measurement ranges for different levels of walkway traction. As with B101.1, this is only possible due to the standard's reliance on a restricted set of specific tribometer models.
- Underwriters Laboratory (UL) 410 *Slip Resistance of Floor Surface Materials*: This standard specifies that floor covering materials, floor treatment materials, and walkway construction materials shall have a COF of 0.5 under material-specific test conditions – all measured using a James Machine in a specific methodology. The James Machine is a non-portable lab-only machine weighing over one hundred pounds.
- ASTM D2047 *Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine*: This standard, which is widely referenced (as will be discussed below), specifies that floor polishes and coatings shall have a dry SCOF of at least 0.5 – using the methodology and equipment (James Machine) specified in the standard only.

Traction Requirements – Past and Present

Though technically not a "requirement", for decades the commonly referenced "safe" traction threshold was a COF of 0.5. This value was recommended (in 1945) by UL's Sidney James. ASTM D2047 dates from 1964 and it mentions (but does not specifically reference) experiential data dating back to 1942; D2047 is in fact the only active ASTM test method that establishes 0.5 as a traction requirement (but only for floor polishes).

It has been widely stated in both general publications and court decisions (e.g. *Phelps v. Stein Mart*, 2011) that ASTM "requires" a traction value of 0.5 *in general* – without the qualifiers documented in D2047. In *Phelps*, for example, two opposing experts agreed that ASTM requires a COF of 0.5 – despite the fact that they were testing a ceramic tile (not a polish coating) and that they both used a test device completely different from a James Machine.

The *Phelps* case is further illustrative in that the opposing experts also agreed that OSHA, ANSI, and UL all *require* a COF of 0.5. OSHA did have a requirement for a slip resistance of 0.5, but this was only for structural steel walking surfaces, and this requirement was rescinded in January of 2006. The sole OSHA walkway traction requirement (0.5 COF) is for manlift platforms in 29CFR1910.68(c)(3)(v) – and this regulation lacks a methodology for verification. UL410 requires a COF of 0.5 but only for surfaces tested with a James Machine to a specific methodology. And, to be precise, ANSI is a standards development organization *accreditor*, not a standards development organization itself. ANSI cannot require a COF value. The ANSI-accredited American Society of Safety Engineers (ASSE) committee that created A1264.2 (as mentioned above) does *suggest* a slip resistance value of 0.5 – without a methodology for verification.

As to other foundations for a traction value of 0.5, human slip research (over the past thirty years) with forceplate analysis of required COF has typically resulted in RCOF values of ~0.20-0.30, with which many practitioners use a 2X safety factor to bring it up to 0.5. Despite the arbitrariness of this safety factor magnitude, this 0.5 value was treated (by some) as a hard number – so 0.48 was dangerous and 0.52 was not (again see *Phelps v. Stein Mart*, 2011). As we will also see, treating 0.5 as a hard yet universal "safe" threshold is not defensible across the range of tribometer designs in use.

How Much Traction Do Humans Need?

Due to the significant problem of human slip incidents, researchers have studied pedestrians of various ages, disabilities, and medical conditions, involved in various activities. This research shows (variously) how much walkway traction pedestrians actually require for walking without concern for traction, or how much traction they utilize when they have some expectation of reduced traction.

Across various studies, typical traction values can be extracted. Referencing five studies, Redfern et al (2001) reported RCOF values of 0.17-0.22 for level surface walking. A study involving young and elderly pedestrians with and without a disability resulted in a mean RCOF of 0.23 in level walking (Burnfield et al. 2005).

As mentioned earlier, such values are commonly referenced in the context of "safety thresholds" for traction in tribometer testing (e.g. approximately doubling the RCOF values to get 0.5). But the amount of traction *used by a pedestrian* is not directly comparable to the amount of traction that can be *measured by a machine*. A study by Powers et al (1999) compared tribometer forces imparted to a forceplate with the tribometer readings themselves, but (comparing with Redfern et al. 2001) the force onset magnitudes and durations are completely different between humans and tribometers.

Note that stairways and bathing surfaces each introduce their own complications to pedestrian traction; this discussion, however, will be limited to level walkways. For further reading on stairway traction see Burnfield et al. (2005), and regarding bathing surface traction see Siegmund et al. (2010).

Slip Testing with Humans and Tribometers

It can be seen that human slip research is not a practical way to conduct field testing of in-situ walkway surfaces. This is why tribometers are used for field testing – but tribometers do not slip and fall. The component missing from decades of walkway traction analysis (and testimony) was reliable correlation of tribometer measurements to human slip events. Over the past five to ten years (in the US) there have been efforts to establish such a correlation. European ramp slip studies have formed the basis for new ANSI standards, using slip measurement results in conjunction with a safety factor, and applicable to certain tribometers. New ASTM standards have been based on research at the University of Southern California (Powers et al. 2010), wherein human subjects were used to rank four standardized reference tiles by the type and number of slips on each. Any tribometer able to properly rank and statistically differentiate the four reference tiles can be compared with the USC research. These studies will be discussed further below.

In pedestrian slip research studies, the human subjects typically wear a safety harness with an overhead lanyard attached, in order to prevent them from actually falling if they slip. This again brings up the key issue of expectation. Studies have shown that pedestrians modify their walking gait if they have some expectation they might slip (Li et al. 2006, Beringer et al. 2014). In utilized COF testing, there may be visual warnings of a potentially slippery surface (e.g. walkway glossiness), or the test subjects may know the potential hazard in advance. Cham & Redfern (2002) found a 16-33% reduction in RCOF for pedestrians that were unsure of which of several walkway contaminant conditions they would encounter. In ramp traction testing, the "pedestrians" know they will slip, and they are in fact trained to walk in certain ways that may not be representative of normal ambulation. Level walkway traction testing may be configured to reduce both the test subjects' expectation that they may slip and their knowledge of slippery conditions (Powers et al. 2010).

Tribometers and the Significance of Their Results

Overview of Different Tribometer Features and Types

The tribometers described below are portable, common, and available for purchase in the United States. Certain tribometers may be used on stairs; within these, some may only function in specific areas or directions on the stair tread. Certain tribometers may be used on ramps and slopes, though measurements typically need to be adjusted for the effects of gravity through trigonometry-based correction factors (see Templer 1995).

Tribometer Testfeet

Tribometers contact the walkway surface with a "testfoot". Some tribometers use a laboratory-grade standardized rubber called Neolite as the testfoot material, while others use styrene butadiene rubber (SBR), which is a common polymer used for footwear outsoles. Some older tribometers are used with leather testfeet despite the inconsistencies inherent in leather as an organic material.

It is of note that the testfoot material must actually contact the walkway surface for the measurements to be meaningful. Using a tribometer to test loose gravel, broken glass particles, or peanut shells is typically not scientifically supportable, nor is it likely to be backed up by human slip research. Hard particles of gravel or glass raise the testfoot above the walkway surface, and the resultant rolling friction will vary with the distribution of the particles. Peanut shells (and other crushable contaminants) will disintegrate to varying degrees, depending upon the contaminant and the tribometer forces applied. This affects both the relevance and reliability of such testing.

Drag Sled Tribometers

Drag sleds are so named because they "drag" a weighted testfoot across the walkway surface of interest. There are manually-operated and motorized drag sleds available. Manual (and some motorized) drag sleds are used for static COF testing in which the testfoot is momentarily motionless (or "static") against the walkway surface; this has been known for decades (see Brungraber 1976) to affect accuracy of measurement due to molecular bonding or adhesion (sometimes called "sticktion") of the testfoot to the walkway surface while stationary. In addition to the portable tribometers described in this section, the James Machine exhibits adhesion. Adhesion is particularly problematic in wet testing; it may result in artificially high measurement values - walkways will test as being "safer" than they are. Some tribometer standards and manufacturers state that SCOF tribometers are only to be used on dry walkway surfaces. Another issue with manual drag sleds is that the operator can affect the measurement results by varying the manner in which the device is actuated – whether intentionally or unintentionally.

Certain motorized drag sleds can perform dynamic COF testing, which typically is not subject to adhesion.

Drag Sled Models:

- Horizontal Dynamometer Pull-Meter – This manual drag sled (which can be home-made) is described in the withdrawn ASTM C1028 standard test method; for years it was the primary device (and test method) for SCOF testing of ceramic tiles. It uses a 3" x 3" testfoot beneath a 50 pound weight. Many traction specs for tiles still reference C1028 testing, even though tile industry standards no long reference SCOF measurements.
- Regan Scientific: BOT-3000 and BOT-3000E – This is a motorized drag sled that uses powered wheels to travel across the walkway. It uses a 0.12" x 1.1" testfoot. It can be used in both static and dynamic COF modes. The BOT-3000 ("or equivalent") is specified as the tribometer to use for dynamic COF testing in the ANSI/TCNA A137.1 standard for ceramic

tile. It is also an "approved" tribometer for the ANSI/NFSI B101 standards published by the National Floor Safety Institute.
- CSC Force Measurement: Horizontal Pull Slipmeter (HPS) – This SCOF tribometer uses a cable and winch system to pull a manual drag sled. It uses three ½" diameter discs for testfeet. ASTM F609 specifies its use for dry walkway testing. The device measures "slip index", which (per the standard) is a multiple of SCOF.
- American Slip Meter: ASM 825 and 825A – This manual drag sled uses three 1/2" diameter discs (like the HPS) as testfeet, and measures static COF.

Articulated-Strut Tribometers

Articulated strut tribometers apply testfoot loads through an angled strut that "kicks out" when a testfoot slip occurs. The designs avoid adhesion by simultaneously applying the horizontal and vertical components of the walkway surface load to the testfoot.

Articulated-Strut Tribometer Models:

- Slip-Test Walkway Tribometers: Mark IIB and Mark IIIB Portable Inclinable Articulated-Strut Slip Tester (PIAST) – These tribometers use a sliding 10-pound weight (Mark IIB) or compression spring (Mark IIIB) for actuation of a 3" x 3" testfoot. The devices measure transitional COF, and can be used on sloped walkways.
- Excel Tribometers: English XL Variable Incidence Tribometer (VIT) – The tribometer uses a CO2 cylinder for pneumatic actuation of its 1.25" diameter testfoot. There are two primary models, one with a manual pneumatic trigger and one with a "sequencer" that automates some aspects of trigger actuation. The device measures "slip index", and can be used on sloped walkways.

Comments on the "Interchangeability" of Tribometers and Their Measurements

The layouts, testfoot geometries, and functional characteristics of the above-mentioned tribometers all differ significantly. Given that friction measurement is empirical, with the results highly dependent upon the test apparatus used, it should be obvious that each tribometer design can be expected to reveal significantly different measurement values (compared to other tribometer designs) even when testing the same walkway surface. Nevertheless, there is still a widespread belief that the commonly mentioned "minimum COF" value of 0.5 is universally applicable regardless of which tribometer is used for measurement. This fallacy defies basic physics. If this fallacy were true, all tribometer designs would have to provide identical results on the same surface, regardless of the surface, and all individual units of a tribometer design would need to provide identical results as well. An illustration of this fallacy can be seen in Powers et al. (2010), in which eleven different tribometer designs were operated on the same four surfaces – and on the safest surface, the traction measurements varied from 0.24 to 0.94. It would be convenient (and much easier to explain) if one traction threshold measurement value was universal, but it is not scientifically supportable. One cannot specify a traction threshold value to be achieved without also specifying the tribometer and methodology to be used.

It is also of interest that some tribometer users (and manufacturers) claim that their tribometer Brand A can test a walkway in accordance with a standard that *requires* tribometer Brand B – as was discussed earlier ref *Phelps v. Stein Mart*.

The Significance of Tribometer Results

Apart from strictly comparative studies, the usefulness of a tribometer is only to the extent that it is correlated to human slips. There are several key elements to using a tribometer (a machine) in an attempt to evaluate the walkway traction available to a human. These elements include:

- Element 1: Is there a reliable correlation between the tribometer's measurements and actual human slip experiences?
- Element 2: Has the tribometer undergone studies to evaluate how repeatable its measurements are – will it provide consistent measurements test after test?
- Element 3: Has the tribometer undergone studies to evaluate how reproducible its measurements are – from user to user and machine to machine?
- Element 4: Was the tribometer used for a particular analysis operated according to the methodology applicable to the repeatability and reproducibility studies?

Element 1: Is There a Reliable Correlation Between the Tribometer's Measurements and Actual Human Slip Experiences?

With human slip studies, perhaps the most conservative goal is to evaluate how much traction is needed by a pedestrian who is unaware of the possibility of slipping. As discussed, RCOF research values of about 0.25 are often referenced by walkway auditors in their rationalization (using a safety factor of 2) of choosing the historical and anecdotal COF value of 0.5 as the "standard" minimum amount of traction their tribometer should measure on a surface with adequate traction. But a surface that measures 0.5 on one tribometer model likely will not measure at 0.5 on a different tribometer model – even with highly repeatable/reproducible tribometers – so simply creating a universal "safety factor" does not work as a correlation between slip research and tribometry. Somewhat more complex correlations between human slips and tribometer measurements have been made in different ways.

European entities (ref Bonig 1996, Sebald 2009) have defined reference tiles that have "known" traction, based on human slip testing on ramps and measurement with specific tribometers. The entities then require the use of specific tribometers capable of measuring these "known" surfaces as having the "correct" value. The ANSI/TCNA A137.1 and ANSI/NFSI B101.3 standards rely on this research and certain associated tribometers including the BOT-3000.

Another method of correlation (not dependent upon specific tribometers) has been through the level walkway traction research studies done at the University of Southern California (Powers et al. 2010). The research involved test subjects walking across four different standardized walkway tiles, with each tile having a different wet traction. The number of no-slips, heel-slips, and toe-slips on each tile was recorded – through this, the human test subjects ranked the surfaces for slipperiness, with statistical differentiation. ASTM F2508 is based on the Powers (2010) research and formalizes that tribometer "Validation" is achieved when a tribometer model can rank and differentiate a duplicate set of the four standardized tiles in the same manner the USC pedestrians did. Certain configurations of the English XL, Mark IIB, and Mark IIIB tribometers are advertised as having been validated to ASTM F2508.

Both correlation methods are predicated on the assumption that the standardized tiles are indeed duplicates (from a traction perspective) of the ones used in the human slip research.

Element 2: Has the Tribometer Undergone Studies to Evaluate How Repeatable Its Measurements Are – Will It Provide Consistent Measurements Test After Test?

A statistical evaluation of a tribometer's repeatability would be consistent with normal scientific practice. All measurement devices will have random and systematic error, and these measurement errors must be understood if assertions about the safety of a walkway are based on those measurements. Statistical analysis of repeatability may be done through repetitive tribometer measurements taken in one sitting by one operator. The Validation procedure in ASTM F2508 requires 40 tribometer testfoot slips on each of the four standardized reference tiles; assuming a Gaussian distribution of the data points, the standard deviation of the mean can be calculated for each reference tile. A large repeatability standard deviation points to significant variability in these measurements. Many tribometer models have not undergone a published repeatability study.

Element 3: Has the Tribometer Undergone Studies to Evaluate How Reproducible Its Measurements Are – From User to User and Machine to Machine?

Repeatability addresses the measurement results obtained by one operator using one tribometer in one session of testing. This does not mean that different operators or even different units of the same tribometer model will provide comparable results. The issue of reproducibility has relevance in litigation, as to whether other parties can "reproduce" the testing of one expert.

Many technical fields utilize an Interlaboratory Study (ILS) for evaluating both the repeatability and the reproducibility (together known as the "precision") of the test method. The test method, in this case, will bring along with it the tribometer operating method, walkway surface preparation methods, contaminants to use, etcetera, so the ILS is evaluating the variability inherent in the entire methodology, not just the tribometer. In the ILS (ref ASTM E691), typically 6 to 30 independent labs will test the same samples; the labs should have different operators and different units of the test equipment (in this case, tribometers and testfeet). The reproducibility statistics, also assuming a normal distribution, will show the scatter of measurement results due to the variability between different operators and different units of the tribometer. A high value for the reproducibility standard deviation may reduce the "certainty" of the conclusions that can be drawn from analyses using that tribometer model. Tribometer "certification" to ASTM F2508 requires that an Interlaboratory Study be conducted in accordance with ILS standard practice ASTM E691, and that the results and data from the ILS are made publicly available. One configuration of the Mark IIIB tribometer is advertised as having been certified to ASTM F2508.

It is of note that few tribometer models have undergone a published Interlaboratory Study. There is no "passing grade" with an ILS - the statistics are what they are, and some ILS results are never published because they are not considered to be favorable.

Element 4: Was the Tribometer Used For a Particular Analysis Operated According to the Methodology Applicable to the Repeatability and Reproducibility Studies?

This ties the other three elements together. For the human slip correlation and the repeatability/reproducibility studies to be relevant to an analysis, they must all have been conducted with a consistent configuration of tribometer/testfoot, using a consistent operational methodology. If the tribometer/testfoot configuration is not the one correlated to human slips, or if the referenced human slip research is technically questionable, the foundations for assertions about a walkway's traction are compromised. If there is no reproducibility analysis, or if the ILS method was questionable, the ability of the operator to claim their tribometer measurements relate to any benchmark is reduced.

Traction Thresholds

<u>The Need for Traction Thresholds</u>

It has been discussed in this paper that the historical 0.5 COF "safe" threshold is technically insupportable. But the benefits in having "safe" traction thresholds are clear – without a consensus-approved threshold determination, there is no target for how much traction a walkway should have for a particular application. Traction thresholds, if clearly expressed, can be used by designers, architects, insurance underwriters, and property holders for evaluating and selecting appropriate walkway materials and flooring. Traction thresholds also have obvious uses for forensic professionals, claims administrators, and safety managers. There are "modern" traction thresholds both in place and in the works, aligned with the two discussed methods for correlation of tribometer measurements to human slips:

Ramp Slip Research-Based Traction Thresholds

- ANSI/TCNA A137.1: This standard has established a traction threshold for ceramic tile. The BOT-3000 tribometer is calibrated to one reference tile available in duplicate from TCNA. The A137.1 methodology underwent an Interlaboratory Study, and there is reference to specific European ramp traction threshold studies. The standards committee has chosen a minimum threshold value of 0.42 for wet DCOF, with some caveats.
- ANSI/NFSI B101.3: This standard establishes ranges of wet DCOF measurement values to represent different traction threshold levels, also with some caveats. The standard states that any NFSI "approved" tribometer can be used with it, though the measurement and precision differences between "approved" tribometers are currently not published. These tribometers are calibrated to one reference tile available in duplicate from NFSI. The B101.3 standard references European ramp traction threshold studies.

Level Walkway Slip Research-Based Traction Thresholds

- Under development from ASTM are standards for establishing traction thresholds and a walkway material traction rating system. The traction thresholds will be tribometer-specific, due to operational differences between tribometers as discussed earlier – though any tribometer capable of certification to ASTM F2508 can be used. The threshold values will be based on Interlaboratory Study-derived mean slip resistance values for one of the ASTM F2508 reference tiles. This mean value will be adjusted through the use of a multiplier of the ILS reproducibility standard deviation value for that tile. The walkway material traction rating system, at the time of this writing, will likely establish grades (e.g. A, B, C) for walkway materials that meet or exceed the tribometer-specific threshold by certain percentage levels. The specifics of the pending standards are subject to change.

Litigation Considerations

It is a complicated task to understand all the elements discussed and offer defensible (and understandable) opinions on walkway traction. There are many opportunities for an expert (or an opposing expert) to miss something. As such, it is important for the expert to know his or her methodology intimately – and to know the opposition's methodology as well.

There remain many "experts" who claim that walkway traction testing is too undefined and that there is no one "right answer". But there cannot be one "right answer" – which is not uncommon in scientific study – and there is a vast body of research, standards activities, and scientific methodologies that can provide useful information.

As to courts deciding whether walkway traction analysis testimony should be accepted as reliable, there will be inertia and precedent set by past court findings wherein a methodology now known to be flawed was the "state of the art" at the time – compare *Phelps v. Stein Mart* with *Michaels v. Taco Bell* and *Kill v. City of Seattle*. Fortunately, more-defensible methodologies have evolved and can be used to counter unsupported assertions made by "experts" in this field. Effectively countering obsolete expertise will further the causes of establishing defensible methods as the "new state of the art", and reaching just resolutions to claims and lawsuits.

Disclosure

John Leffler, PE is a Forensic Mechanical Engineer with FORCON International, and he is also Lead Engineering Consultant to Slip-Test Walkway Tribometers.

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