Slips and Falls

State of the Art in Slip-Resistance Measurement

A review of current standards and continuing developments

By Steven Di Pilla and Keith Vidal

FALLS IN THE WORKPLACE are the number one preventable loss type; in public places falls are far and away the leading cause of injury. More than one million people suffer from slip, trip or fall injuries each year, and more than 16,000 die as a result of falls, second only to automobiles as a cause of death. Falls are estimated to cause at least 17 percent of occupational injuries, and more than 18 percent of public-sector injuries (NSC 9). In addition, it is well known that falls are underreported, since accident rates are normally classified by injury type rather than cause of injury in workers' compensation and NEISS statistics.

Because one can measure slip resistance in many ways, no universally recognized method of measurement has yet been established. A recent count (1996) identified at least 60 different slipmeters that have been invented since the first known device of this type (the Hunter Machine) was developed in the 1930s (Strandberg 213-214). However, of the most widely used slip-resistance measurement devices (or tribometers), only two have sufficient credentials to be used on dry and contaminated surfaces.

Another problem is that the output of these instruments doesn't always agree and no method exists to correlate the results of one class of tribometer with another. Compounding this problem is the misinformation used to market several instruments and the inaccurate literature provided with certain flooring, floor treatments and footwear.

The terms "static coefficient of friction" (SCOF) and "slip resistance" are often used interchangeably. While SCOF refers more to the theoretical and to laboratory testing, the term slip resistance includes variables found in field testing (such as contamination of the floor or shoe surface). While older standards refer to this measurement as SCOF, emerging standards are using the term slip resistance.

Slip-resistance rating ranges from a minimum of zero to a maximum of one. The closer the rating is to zero, the greater the relative slipperiness of the surface tested. For example, a rating of 0.1 indicates very low slip resistance, while a rating of 0.9 indicates very high slip resistance.

Steven Di Pilla, ARM, AIC, *is director of product development and training for Risk Control Services at ESIS Inc. in Philadelphia. He is responsible for identifying and filling staff needs for all lines of business—by researching technical issues and developing references, training and certification programs, standards, loss analyses and external publications. Di Pilla recently conducted a statistical research study comparing 10 slip-resistant floor-treatment products. He is a professional member of ASSE's Penn-Jersey Chapter.*

Keith Vidal, P.E., *is founder and principal of Vidal Engineering Inc., which specializes in consulting with manufacturers of slip-resistance-related products, safety and claims management professionals, maintenance and housekeeping organizations, insurance companies and attorneys. Vidal is a member of several ASTM committees that are involved with pedestrian safety. He is also chair of ASSE's Standards Development Committee, serves on ASSE's Governmental Affairs Committee and has written and presented many articles and studies on the subject of slips, trips and falls. He is a professional member of ASSE's St. Louis Chapter.*

Testing for Slip Resistance

Many slip-and-fall incidents occur as a result of contact with a spot on the floor surface that is unexpectedly slippery, often due to moisture. Currently, only two devices have an ASTM F-13 standard for wet testing: the portable inclineable articulated strut tribometer (PIAST, aka Brungraber

Mark II) and the variable incidence tribometer (VIT, aka English XL). Many independent studies have verified the reliability of these devices for wet testing. From forceplate analysis and roughness measurement to testing in workshops conducted by the American Society for Testing and Materials (ASTM) and others, the PIAST and VIT have proven to produce repeatable and reproducible results (Powers 373).

Why can these devices meter wet surfaces more accurately than others? They avoid "sticktion" (also known as "stick-slip"). Sticktion is the result of water being squeezed out of the interface (between the test foot and the walkway surface), creating a temporary bond between these surfaces. Test results of devices subject to sticktion can produce unrealistically high slip-resistance readings on wet surfaces—sometimes producing results indicating greater slip resistance than the same surface when metered dry. Sticktion is a byproduct of residence time, which is any delay between the instant of surface contact and the application of horizontal force (Kulakowski 235). The PIAST and VIT avoid sticktion by applying the horizontal and normal forces simultaneously, thus eliminating residence time and sticktion. A similar phenomenon cited in the literature relating to dry conditions is referred to as "adhesion" (Brungraber). While all F-13 ASTM-recognized tribometers can be used for dry testing, remember that dry contaminants can alter test results.

ASTM Tribometer Standards

ASTM, a nationally recognized consensus standards-making organization, is active in the development of slip-resistance-related standards. It currently has eight active standards for six different slipmeters, which include the build-it-yourself horizontal dynamometer pullmeter method (also known as the "50-pound monster"), the no-longer-manufactured horizontal pull slipmeter (HPS), the laboratory-only James Machine, and the proprietary PAST, PIAST and VIT devices.

Some methods are approved only for specific uses. For example, the standard for the horizontal dynamometer pullmeter method (C1028) specifies that this device is approved for use only on ceramic tile and like surfaces. Therefore, using it to test walkway surfaces other than ceramic tile is of questionable validity since the device has been evaluated and approved for use only on this specific material.

Readings on the same surface under substantially identical conditions with two different types of instruments can result in different slip-resistance determinations. For example, tests performed with an HPS and a James Machine on the same surface and under the same conditions can produce different results. Currently, there is no known correlation between these devices; this is because test methods have their own set of biases and operator variability issues, and also because friction is, in part, a property of the system used to measure it (Marpet).

ASTM F-13 Tribometer Standards

The title of the ASTM F-13 technical committee is Safety and Traction for Footwear. This name is a bit misleading, since its scope also includes safety and traction for walkway surfaces, as well as practices related to the prevention of slips and falls. Currently, five tribometers have an F-13 standard.

James Machine

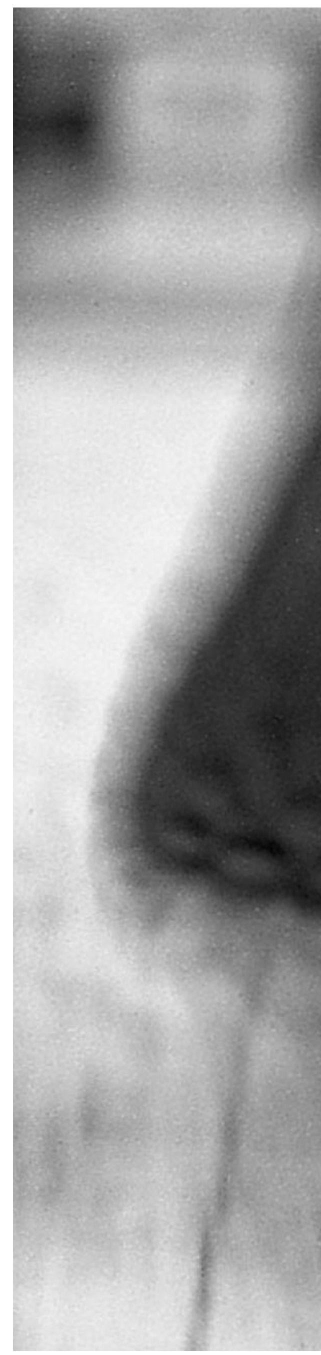
The James Machine is a laboratory-only device for dry testing in accordance with standard F489, Standard Test Method for Using a James Machine. Sidney James of Underwriters Laboratories developed this early slipmeter in the 1940s. As an articulated strut class of tribometer, the James Machine applies a known constant vertical force to a test pad (leather when evaluating flooring materials), then applies an increasing lateral force until a slip occurs (Sacher 33).

The James Machine has several inherent biases, prompting users to make modifications in an attempt to achieve good repeatability on a single instrument and good correlation between several machines. The device needs continuous maintenance and adjustment, in part due to the required release of an 80-lb. weight (ASTM D6205).

Horizontal Pull Slipmeter

This device is approved for dry testing only under standard F609, Standard Test Method for Using a Horizontal Pull Slipmeter (HPS). Charles Irvine developed this instrument in the 1960s. The basic principle of the HPS, a dragsled class of slipmeter, is the pulling of a footwear or surrogate material against a walkway surface under a fixed load at a constant velocity. The HPS consists of a 10-lb. weight onto which a slip index meter is attached. This component is attached to a nylon string and pulled by a capstan-headed motor. Aside from the problem of sticktion that makes this device unreliable on wet surfaces, it raises other concerns.

- Use of a spring combined with the analog indicator makes obtaining a definitive reading difficult.
- Lack of structure between the motor and the meter/weight (a nylon string) can result in operator variances in the application of lateral forces.

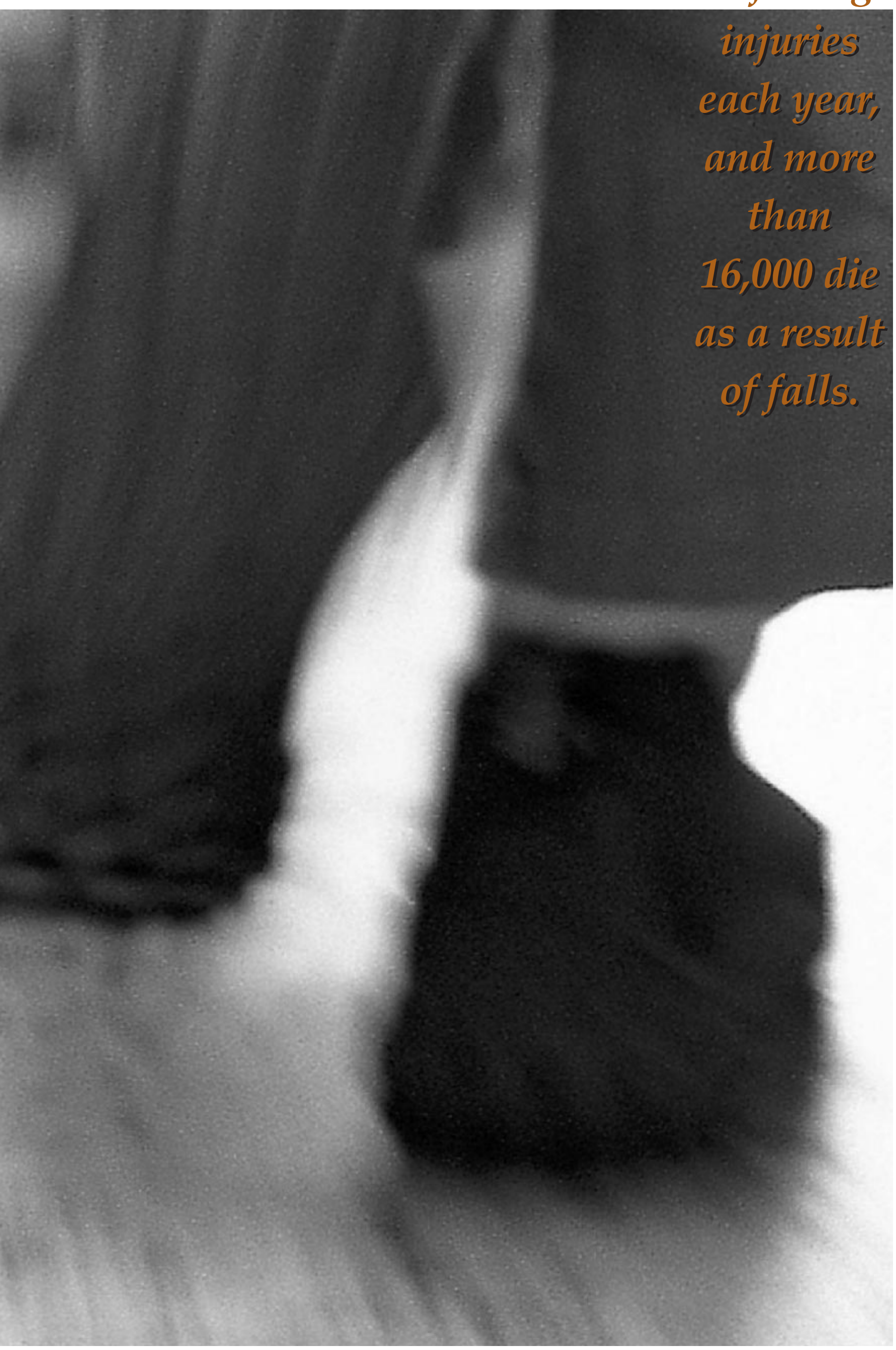


• Although other devices are based on similar dragsled technology, the ASTM-approved version of the HPS is no longer in production.

NBS-Brungraber (Mark I)

This device is also approved for dry testing only as the portable articulated strut tester (PAST) under standard F1678, Standard Test Method for Using a Portable Articulated Strut Slip Tester. While working for the National Bureau of Standards (NBS, now known as the National Institute for Standards and Technology) in the 1970s, Robert Brungraber developed this tester. Similar in principle to the James Machine, the Mark I is also an articulated strut instrument approved only for dry testing. It is generally used with a leather test pad. Unlike the James Machine, however, it is portable and can test actual floors; it uses a graduated rod that provides a direct reading from the device. Some calculation is required to convert this to a slip-resistance measurement (Brungraber). Although the Mark I is still in use, Brungraber's subsequent invention, the Mark II, has gained wider acceptance.

> *More than one million people suffer from slip, trip or falling injuries each year, and more than 16,000 die as a result of falls.*



Brungraber Mark II

Approved for dry and wet testing as the PIAST under standard F1677, Standard Test Method for Using a Portable Inclineable Articulated Strut Slip Tester, this device was invented by Brungraber in the 1980s. A gravity-based articulated strut device designed to avoid sticktion, the Mark II enables users to reliably meter wet surfaces. It does so by eliminating the residence time (or time delay) between the application of the vertical and horizontal forces. Like the Mark I, it is a portable device. It uses a 10-lb. weight on an inclineable frame, with a test foot suspended just above the walkway surface. Each time the angle is set to a more-horizontal position, the weight is released, until a slip occurs. The slip-resistance reading can be taken directly from the instrument.

English XL

The English XL is approved for dry and wet testing as the VIT under standard F1679, Standard Test Method for Using a Variable Incidence Tribometer. In the early 1990s, William English developed this device, an articulated strut device similar in principle to the James Machine and the Mark II. Unlike those devices, the English XL does not rely on gravity, but is powered by a small carbon dioxide cartridge at a set pressure. This feature ensures consistent operation by the application of uniform force for each test, and it permits reliable metering of inclined surfaces such as ramps (English). Like the Mark II, the application of vertical and horizontal forces is simultaneous, thus avoiding residence-time and permitting reliable measurement of wet surfaces (Powers 373).

Test Pad Materials

Various materials have been used to test for slip resistance, including leather, Neolite® test liner, and various rubbers. Debate continues regarding the most-suitable material.

Neolite® Test Liner

• Despite protests to the contrary, Neolite® was at one time used by the footwear industry as a heel material. Documents from the U.S. Trademark Electronic Search System verify that this material was registered in 1953 by the Goodyear Tire & Rubber Co. for "soles and heels composed of an elastomer and a resin."

• Material characteristics do not change under normal conditions, regardless of wear or moisture.

• Its traction properties are in the median range of commonly used shoe-bottom materials (Goodwin).

• It has been proven reliable and repeatable over many years in service as a friction pad material, as the

SH&E professionals are wise to be wary of instruments and test methods not supported by a nationally recognized consensus organization such as ASTM.

material of choice for the horizontal pull dynamometer pullmeter, HPS, PIAST and VIT (Vidal 80, 815).

Leather

•Leather is not homogenous. In fact, as it is an organic material, each piece of leather could be considered a unique material.

•Leather is highly absorbent and highly sensitive to humidity. Once leather is used for wet testing, its properties are permanently altered (Bowman, "Legal and Practical").

•Leather is also not representative of heel material. Most heels are of a synthetic compound. Essentially, slips occur more on the rubber heels of leather-soled shoes.

•Leather can react differently depending on how worn the material has become.

Rubbers

Various rubber compounds (e.g., 4S, Neoprene, Nitrile) have been proposed (and used) as a friction pad material. In most cases, these have been in relation to overseas test methods such as the pendulum tester and Tortus-type devices (see Overseas Standards). Most rubber compounds have a curing period of six months or more during which they are unstable and, thus, unreliable. In addition, there is no source of a consistent, long-term formulation. Many rubbers are among the most slip-resistant materials currently in use for footwear and can provide overly optimistic readings when assessing the slip resistance of flooring materials (James 14). In contrast, neoprene rubber, a specification of some U.S. government shoes, provides low traction on lubricated surfaces. The impact of wear on rubbers is another variable.

Other ASTM Standards

Some standards relating to the measurement of pedestrian slip resistance/surface traction are the responsibility of other ASTM committees, but are usually intended for merchantability of products. Except for C1028, each specifies devices for which ASTM F-13 standards also exist.

•D2047, Standard Test Method for Static Coefficient of Friction of Polish-Coated Floor Surfaces as Measured by the James Machine, is under the jurisdiction of technical committee D21, Polishes. This standard uses the same apparatus as ASTM F489. As a laboratory-based machine, it can be used only on floor samples, not in-service floors. Since the device is subject to sticktion and specifies the use of leather (the properties of which change when wet, delivering overly optimistic readings), this device should be used only to test dry surfaces (ASTM D2047). Setup instructions have never been standardized, an issue made more complex by the presence of at least four different versions of the James Machine, some of which are no longer commercially available. Despite these shortcomings, the device is still used to validate the merchantability of new flooring materials and treatments.

•D5859, Standard Test Method for Determining the Traction of Footwear on Painted Surfaces Using the Variable Incidence Tester, has been transferred from D01, Paints to ASTM F-13.

•C1028, Standard Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method, is under the jurisdiction of technical committee C21, Ceramic Tile. Although often confused with the F609 HPS device (since it operates in a similar way), the manually operated C1028 is a different instrument—a do-it-yourself device. C1028 contains instructions on how to construct and operate the device, calling for an analog dynamometer, Neolite® test pad and 50-lb. weight (ASTM C1028). Because it is not a manufactured device, most C1028 units are unique, increasing the potential for variability in results. Although it is currently approved for wet testing, like other dragsled technologies, the C1028 method produces erratic results on wet surfaces (Guevin 5).

Plans for the ASTM "Gold" Standard

The ASTM Board of Directors appointed a Slip Resistance Task Group to address various slip-resistance issues. In essence, the documents being considered present a relative ranking. Standards may call for the identification of a set of external calibration material sets (footwear- and walkway-reference materials or surrogates) that represent the range (low to high) of pedestrian slip-resistance situations. Following a detailed procedure, a valid tribometer would be required to rank these material sets in their proper order, thereby developing a calibration curve. Once generated for any apparatus, this curve would then be used to verify the instrument or qualify/measure the slip resistance of surfaces, using the reference set of surrogates. Various surfaces or footwear materials tested would be ranked against this calibration set.

If this approach is technically feasible, ranking results may eliminate the need to reconcile the differences in numeric results of the various tribometers. Work continues on this challenging effort.

Overseas Standards

U.S. standards for tribometers are the result of "full consensus." In the case of ASTM, no more than 50 percent of the committee may be producers, and a wide range of interests are represented, including footwear, flooring, steel, consultants and the general public. This is known as "balancing" a committee so that no one interest group can exert undue influence on how the standard is developed or its requirements. The consensus approach aims to arrive at viable standards that provide protection to the public while being reasonable enough to be implemented by industry.

Overseas standards are a different story, however.

Often, these standards are not developed by consensus, but rather are funded, written and published primarily by commercial groups with vested financial interests in industry-friendly standards. While such organizations may welcome the participation of all parties, they are not required to maintain a specific balance of interests (Bowman "Impact").

Ramp Tests

Ramp tests originated in Germany with a set of DIN (a nongovernmental standards-making organization in Germany) standards, and are now in Australian/New Zealand standards. DIN 51097/51130 requires a number of test subjects to walk on various wet tiles. The angle of the ramp is gradually increased until the person is about to slip. Unfortunately, this approach raises several issues. Experts agree that a person's awareness of a potentially slippery surface influences the way s/he traverses that area. For example, if ice or water are present, a person will adjust gait accordingly and likely cross the surface without incident. It is when a person is unaware of the hazard and expects the level of traction to continue that slips are most likely to occur. That said, let's look at ramp tests.

•People selected to participate in the ramp test will expect a slippery surface and, in anticipation, will change their gait. No amount of preparation or instruction will change that. As a result, they will perform much better on the ramp test than they would when encountering an unexpectedly slippery surface in real life.

•People walk on inclines differently than they do on level surfaces. Slipping at a certain point on an incline cannot be compared in any way to slipping on the same surface were it level (Hughes).

•The test method specifies the use of as few as two test subjects, a statistically inadequate sample to provide a basis for validation of the results (Adams). The two subjects selected could easily be anomalous, thus delivering measurements that bear no resemblance to actual conditions.

In essence, ramp tests involve so many biases and variables that whether they can be considered a viable method for evaluating the traction of level walkway surfaces remains in question.

Pendulum Testers

The basic principle of the pendulum class of slip-resistance tester involves the calculation of friction loss as an indirect measurement of slip resistance. The pendulum is raised to a fixed height above the surface and is swung across it. As the test foot crosses the walkway, a spring presses the foot material against the surface. The rubbing of the foot on the surface results in a loss of energy due to friction determined by the reduced length of the swing. This is then related to the COF (Sigler).

Since its development in the late 1940s, the Sigler pendulum tester has fallen out of U.S. standards for pedestrian slip resistance since its results cannot correlate with human perception of slipperiness. At one time, an NBS standard covered this device and it was also specified in Federal Test Method Standard 501a, Method 7121. Practical problems with such devices include their dynamics and operation. Of particular concern is the excessive velocity at which the machine operates, bearing no relation to that of human ambulation (English). Research conducted in the 1970s by ASTM Task Group 15.03 determined that pendulum devices showed significant variation across the test surface, making a reasonable correlation of these results to a single slip-resistance value impractical (Brungraber). The same conclusion was reached in a separate research project by the NBS in the late 1970s. Usability is also a concern; the device is complex and difficult to operate, so its results are highly subject to operator error (Adler and Pierman 9).

Digitized Dragsleds

The original patent for the Tortus, originally developed by British Ceramic Research Ltd., has expired, but several similar devices are currently in use: the Tortus II (British), Sellmaier (German), FFT (Floor Friction Tester), Gabrielli (Italy) and FSC2000. The Tortus and its progeny are self-propelled electronic devices based on dragsled principles that in no way emulate human ambulation. Test pad material varies (Tortus II uses 4S rubber; Sellmaier uses several different materials). As the test pad is dragged across the floor, it records frictional forces and displays and prints the values. Forceplate data from the 1991 ASTM workshop at Bucknell demonstrate the erratic and unstable output of this class of tester, which produces results similar to the variable results of HPS, another dragsled device, when performing wet testing.

Tortus and like devices have several major disadvantages.

•They are not reliable for wet testing due, in part, to the lack of adequate wheel traction and the problem of sticktion. Even the new AS/NZ 4586 standard (Slip Resistance Classification of New Pedestrian Surface Materials) does not list this device for wet testing due to poor repeatability (Bowman "Tortus"). A study by RAPRA Technology concluded that "the Tortus instrument is not at all reliable in wet conditions" (Hughes and James).

Reducing Slips and Falls in the Workplace

A1264.2 Standand Covers Walking/ Working Surfaces

According to the U.S. Dept. of Labor, 15 percent of accidental workplace deaths are caused by slips, trips and falls, second only to traffic crash fatalities. A1264.2, Standard for the Provision of Slip Resistance on Walking/Working Surfaces, was developed to help SH&E professionals address this problem. The standard defines the term slip resistance and establishes common and accepted practices for providing reasonably safe walking and working surfaces. The standard was approved by ANSI July 2, 2001, with ASSE serving as secretariat for the A1264 Standards Committee.

A1264.2 explores surface characteristics, footwear traction and environmental factors of slip resistance to ensure a safer walking/working environment. It explains floor characteristics, including the installation of mats and runners, controlling access to areas with a slippery environment and providing appropriate signage, footwear properties, such as a shoe's sole design to ensure slip resistance, housekeeping training and maintenance, surface testing equipment and floor selection. The standard is available from ASSE. For more information, visit www.asse.org or call ASSE's Customer Service Dept. at (847) 699-2929; request item #3383.

Slip-and-Fall-Related Standards

American Society for Testing Materials Standards (ASTM)

- **ASTM C1028** Standard Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method
- **ASTM D2047** Standard Test Method for Using a James Machine
- **ASTM D6205** Standard Practice for Calibration of the James Static Coefficient of Friction Machine
- **ASTM D5859** Standard Test Method for Determining the Traction of Footwear on Painted Surfaces Using the Variable Incidence Tester
- **ASTM F489** Standard Test Method for Using a James Machine
- **ASTM F462** Standard Consumer Safety Specification for Slip-Resistant Bathing Facilities
- **ASTM F609** Standard Test Method for Using a Horizontal Pull Slipmeter
- **ASTM F1677** Standard Test Method for Using a Portable Inclineable Articulated Strut Slip Tester
- **ASTM F1678** Standard Test Method for Using a Portable Articulated Strut Slip Tester
- **ASTM F1679** Standard Test Method for Using a Variable Incidence Tribometer

Deutsches Institute fur Normung e.V (DIN) Standards

- **DIN 51097** Testing of floor coverings; determination of the anti-slip properties; wet-loaded barefoot areas; walking method; ramp test (November 1992).
- **DIN 51130** Testing of floor coverings; determination of the anti-slip properties; workrooms and fields of activities with raised slip danger; walking method; ramp test (November 1992).

•There are no known calibration procedures or requirements.

•As yet, no U.S. standard recognizes this class of tribometer as a valid test device, nor are any plans underway to develop one.

Conclusion

SH&E professionals are wise to be wary of instruments and test methods not supported by a nationally recognized consensus organization such as ASTM. Some slip-resistance measurement instruments have been portrayed as standardized devices. While ASTM recognizes several test instruments for metering clean, dry surface conditions, only two tribometers have been proven reliable for wet and contaminated testing: PIAST (Mark II) and the VIT (English XL). Slip-resistance standards from overseas may have little applicability in the U.S. because they may not be developed by consensus; there is little agreement between European Union countries regarding a unified approach; and most of these technologies have already been explored by U.S. standards organizations.

ASTM's effort to establish a single standardized test method, independent of test instruments, promises to resolve longstanding inconsistencies in the measurement of slip resistance between technologies. This "performance-based" approach would permit any instrument to be used, providing it could demonstrate reproducible and accurate test results on external calibration materials. ■

References

Adams, N. "Slips and Falls: Some Arguments About Measuring Coefficients of Friction." University of NSW, 1997.

Adler, S.C. and B.C. Pierman. "A History of Walkway Slip-Resistance Research at the National Bureau of Standards." Gaithersburg, MD: National Bureau of Standards (NBS), 1979.

Bowman, R. "The Impact of New Standards on the Specification of Tiling Systems and Products." Dickson, Australia: Commonwealth Scientific and Industrial Research Organization (CSIRO), 1995. <http://www.infotile.com/services/techpapers/95tilex.shtml>.

Bowman, R. "Legal and Practical Aspects of Problems Arising from Slippery Floors." Dickson, Australia: CSIRO.

Bowman, R. "The Tortus Floor Friction Tester: Round Robin Tests." In *Ceramics: Adding the Value: AUSTCERAM 92,* M.J. Bannister, ed. Dickson, Australia: CSIRO Publications, 1992.

Brungraber, R.J. "National Bureau of Standards Technical Note 953: A New Portable Tester for the Evaluation of the Slip-Resistance of Walkway Surfaces." Gaithersburg, MD: NBS, July 1977.

English, W. *Pedestrian Slip Resistance: How to Measure It and How to Improve It.* Alva, FL: William English Inc., 1996.

Goodwin, V.D. "Slip and Fall Accidents: Floor Testing." March 1999. <http://www.mde.cc/publications/slipfall.html>.

Guevin, P.R. "Status of Skid and Slip Resistance Testing Relatable to Painted Floors."

Hughes, R.C. and D.I. James. "Slipping Determinations: Magic and Myth." Undated paper. Shawbury, U.K.: RAPRA Technologies.

James, D.I. "A Standard Slider for Slip Measurements." *Polymer Testing.* 8(1989): 9-17.

Kulakowski, B.T., et al. "Evaluation of Performance of Three Slip Resistance Testers." *Journal of Testing and Evaluation.* 1989.

Marpet, M.I. "Comparison of Walkway Safety Tribometers." *Journal of Testing and Evaluation.* 24(1996): 245-254.

National Safety Council (NSC). *Accident Facts.* Itasca, IL: NSC, 1999.

Powers, C.M., et al. "Repeatability and Bias of Two Walkway Safety Tribometers." *Journal of Testing and Evaluation.* 27(1999): 368-374.

Sacher, A. "Slip Resistance and the James Machine 0.5 Static Coefficient of Friction Sine Qua Non." *ASTM Standardization News.* Aug. 1993: 52-59.

Sigler, P., et al. "Measurement of the Slipperiness of Walkway Surfaces." National Bureau of Standards NBS RP1879. Vol. 40, 1948.

Standards Australia. "Slip Resistance Classification of New Pedestrian Surface Materials." AS/NZS 4586:1999. Sydney, Australia: Standards Australia, 1999.

Strandberg, L. "Ergonomics Applied to Slipping Accidents." In *Ergonomics of Workstation Design.* London: Butterworth, 1983.

Vidal, K. "Slips, Trips and Falls." In *Safety Management Handbook.* Riverwoods, IL: CCH Inc., 2000.

Your Feedback

Did you find this article interesting and useful? Circle the corresponding number on the reader service card.

RSC#	Feedback
53	Yes
54	Somewhat
55	No