May 2023

CPSC Staff[1] Statement on Forcon International report "Task I Report"

The voluntary standard ASTM F462 *Standard Consumer Safety Specification for Slip-Resistant Bathing Facilities* has been withdrawn since 2016. To support the work of CPSC staff in this area and the ASTM Subcommittee's consideration of a replacement standard, CPSC awarded contract 61320621P0035 to Arizona State University (ASU) to perform three tasks:

1) Conduct literature review of existing standards and studies and determine appropriate tribology method to evaluate bathing surfaces. (ASU subcontracted this task to Forcon International)
2) Develop test surfaces for tribometer measurement and human slip research to evaluate slip-resistance on bathing surfaces. (ASU subcontracted this task to Forcon International)
3) Conduct human research study to evaluate slip/fall on test surfaces developed in Task 2, with focus on older populations.

The report titled, "Task I Report," presents the results of work by Forcon International on Task 1. The contractor reviewed domestic and international standards related to methods of evaluating slip resistance of surfaces and determined that the British pendulum is the appropriate method to characterize a bathing surface because it provides repeatable results. The pendulum test swings a rubber slider across a surface and provides a pendulum test value (PTV) that represents energy dissipation.

This work will assist CPSC staff as they continue to work to improve the safety of bathing surfaces, including working with the ASTM F15.03 Subcommittee on Bathtub and Shower Structures and other interested parties.

[1] This statement was prepared by the CPSC staff, and the attached report was produced by Forcon International for CPSC staff. The statement and report have not been reviewed or approved by, and do not necessarily represent the views of, the Commission.

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CPSC PROJECT 61320621Q0068

TASK I REPORT

9/14/2022– John Leffler, PE

1. Introduction
   1.1. The goals of and context for this project are described in the Performance Work Specification (PWS) "Background" section. A key purpose for the project is to provide the technical foundations required for a modernized version of the obsolete and withdrawn ASTM F462 standard for bathing surface friction. This planned modernized version is referred to as "F462+".
   1.2. The PWS describes the overall scope of Task I as well as its ten delineated subtasks. The Contractor responses to these subtasks incorporate qualifiers defined in the bid documents accepted by CPSC.
   1.3. This report PDF includes bookmarks to reference materials and subtask reports already completed. Click on the bookmark menu in Acrobat to view.
2. Background
   2.1. The overall project's work is split into two general technical fields as follows:
      2.1.1. **Human testing**: Multi-subject human testing of the barefoot friction of "reference surfaces" (RSs) intended to represent typical bathing surface (bathtub and shower standing surface) environments. The human testing is intended to be conducted utilizing test subject populations representative of those more affected by bathing surface slip events. This work is conducted by Arizona State University (ASU).
      2.1.2. **Tribometry methodology**: Development of the needed RSs in conjunction with development of a practicable friction test methodology suitable for evaluation of new and installed bathing surfaces without the need for convening scenario-specific human testing. The RSs and method are interrelated; neither can be standalone. This work is conducted by Forcon International.
   2.2. Task I as stated in the PWS is largely focused on review of existing literature, standards, and methods. Some subtasks were focused on such review (Tasks I-1, 2, 3, 4a, 4d) while others (Tasks I-4b, 4c, 5c) could not be met using existing information. Tasks I-5a and 5b were not quoted.
3. Methods

3.1. Task I-1: Review of ASTM F462 and comparable standards for adult bathing surface slip resistance.

   3.1.1. See **Task I Plan** section 1 and **Task I-1 Report**.

3.2. Task I-2: Review of industry and international standards for flooring friction requirements.

3.2.1. See **Task I Plan** section 2 and **Task I-2 Report**.

3.3. Task I-3: Review of historical biomechanics research studies concerning elderly slip/fall on bathing surfaces.

3.3.1. See Task I-3 literature review, provided separately by ASU.

3.4. Task I-4a: Review of tribometers that are applicable for slip-resistant testing, for which there is data on repeatability and reproducibility (R&R).

3.4.1. See **Task I Plan** section 4. As this task's R&R research was part of the research for Task I-4b, there was no separate report for Task I-4a. See content below.

3.5. Task I-4b: Determine tribometers suitable for measuring bathing surface friction in this project.

3.5.1. See **Task I Plan** section 5, **Task I-4b Matrix**, and content below.

3.6. Task I-4c: Plan for evaluating tribometry procedure repeatability and reproducibility.

3.6.1. See **Task I Plan** section 6 and content below.

3.7. Task I-4d: Requirements for RS usage as verification surfaces to calibrate and validate tribometers.

3.7.1. See **Task I Plan** section 7 and content below.

3.8. Task I-5a: Not quoted.

3.9. Task I-5b: Not quoted.

3.10. Task I-5c: See **Task I Plan** section 10 and content below.

4. Results

4.1. Task I-1: Review of ASTM F462 and comparable standards for adult bathing surface slip resistance.

4.1.1. See **Task I-1 report**.

4.2. Task I-2: Review of industry and international standards for flooring friction requirements.

4.2.1. See **Task I-2 report**.

4.3. Task I-3: Review of historical biomechanics research studies concerning elderly slip/fall on bathing surfaces.

4.3.1. See Task I-3 literature review, provided separately by ASU.

4.4. Task I-4a: Review of tribometers that are applicable for slip-resistant testing, for which there is data on repeatability and reproducibility (R&R).

4.4.1. As this task's R&R research was part of the research for Task I-4b, there was no separate report for Task I-4a.

4.5. Task I-4b: Determine tribometers suitable for measuring bathing surface friction in this project.

4.5.1. The **Task I Plan** established (in sections 5.1 and 5.2) a selection criteria for candidate tribometers, as follows.

4.5.1.1. Criteria:

4.5.1.1.1. Portability: device less than 50 pounds, self-contained (doesn't require an unusual external power source such as an air compressor or 220V electrical).

4.5.1.1.1.1. Rationale: As the F15.03 standard resulting from this Project is intended to be usable in the field by inspectors and safety professionals, the tribometer would need to be field-deployable without atypical infrastructure.

4.5.1.1.2. Has at least 3 recognized verification surfaces with accepted friction levels reasonably distributed across the tribometer's measurement range.

4.5.1.1.2.1. Rationale: Verification surfaces are used periodically to ensure the tribometer is functioning properly; the performance of an individual tribometer cannot be reliably evaluated only at one point on its measurement scale.

4.5.1.1.3. Has ILS data published for it on multiple surfaces relevant to human slips.

4.5.1.1.3.1. Rationale: There are tribometers on the market for which some level of reliability is implied but not documented. Published ILS data, from testing on identified surfaces, allows others to evaluate the R&R relevant to each identified surface.

4.5.1.1.4. The tribometer design should not be proprietary or under an active patent.

4.5.1.1.4.1. Rationale: Consensus approval of standards is harder to obtain if it appears that one manufacturer or similar entity will be the sole financial beneficiary of the standard's approval. Further, with ASTM's typical application of their regulations, if a proprietary or patented device is required for a standard, the device cannot be mentioned by name in the standard – which keeps the standard from being a standalone document.

4.5.1.1.5. Method of function is not obviously incompatible with slightly concave/convex surfaces or 3D profiled surfaces.

4.5.1.1.5.1. Rationale: Unlike most underfoot surfaces, bathing surfaces typically have slightly concave (or convex) foot contact area geometry (for drainage purposes), and some

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tribometers would not be expected to provide reliable measurements on such surfaces.

4.5.1.1.5.2. Rationale: Embossed plastic and polymer composite bathing surfaces use patterns of "protruding" 3D features to enable draping-related mechanical interlocking of the foot with the surface. However, some tribometer designs have sliders that are too rigid to conform to 3D features. Other tribometer designs have sliders where their typical movement trajectories would be hampered by 3D features in a manner that is not conducive to reliable measurements.

4.5.1.1.6. Has a consensus-approved standard for its use, or alternately, has a test procedure that has demonstrable acceptance in the technical community.

4.5.1.1.6.1. Rationale: It is a complex and process for a tribometer (and associated test procedure) to achieve acceptance in this technical community. A tribometer used for this Project should already be thoroughly vetted in some testing application similar to bathing surfaces, such that a methodological infrastructure exists as a basis for the Project.

4.5.1.2. Point system:

4.5.1.2.1. 0: does not meet

4.5.1.2.2. 1: adequate

4.5.1.2.3. 2: excellent

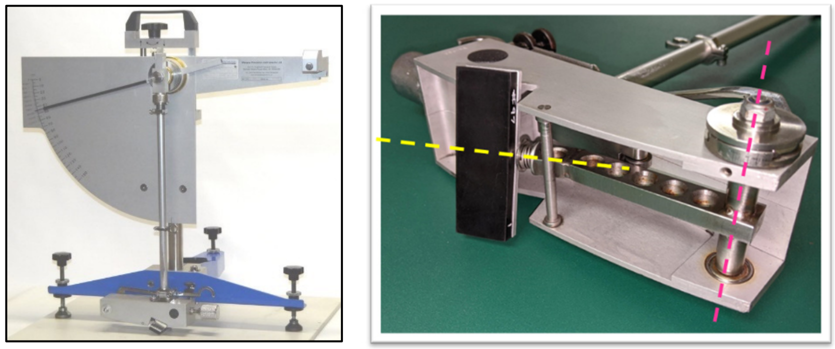
4.5.1.3. See **Task I-4b Matrix** for the selection criteria scoring. References relied upon are in the **Task I-2 report**.

4.5.1.4. The decision structure in the **Task I Plan** was as follows:

4.5.1.4.1. Obtain top three candidate tribometers (2^{nd} and 3^{rd} place as feasible); if one tribometer has a ≥25% higher score than other tribometers, the 2^{nd} and 3^{rd} place tribometers do not progress to the flat vs. concave testing and 3D patterned feature testing described below unless the 1^{st} place tribometer fails one of these two tests.

4.5.1.5. The British Pendulum tribometer scored >25% higher than the other candidates.

4.5.1.5.1. Briefly: the British Pendulum tribometer is a 60+ year old design with dimensional and performance criteria published in numerous standards; it is an "open source" design (unlike most US tribometers which are proprietary). The Pendulum is made by many different manufacturers around the world, and each manufacturer's execution of the design may differ, as the design criteria are limited in scope. That said, the Wessex and Munro designs are common and are in some cases copied by other manufacturers; for example Stanley makes a Munro copy and KSS makes a Wessex copy. The Pendulum uses a spring-loaded slider suspended from a pivoting carriage at the end of a pendulum arm. The slider has two degrees of freedom; it can pivot freely about a longitudinal axis, and its carriage pivots about the spring-loaded lateral axis. See images.



British Pendulum [left], yellow (longitudinal) and pink (spring loaded lateral) axes of slider rotation [right]

The slider is a mounted rectangle of rubber polymer that contacts the surface being tested, and the degree to which the slider slows down (as a result of frictional interaction) is quantified for a friction measurement. It measures energy dissipation due to friction, in short. The measurement scale is 0-150, and the units are PTV (Pendulum Test Value) or BPN (British Pendulum Number); these are equivalent. The Pendulum is cited for use in many standards around the world; it is less popular currently in the US. One reason for this may be that the Pendulum is heavy and bulky, compared to most popular US portable tribometers. The Pendulum, however, has a much deeper base of technical support for reliable usage. A more thorough description of Pendulum apparatus and usage can be found in Section 3 of the UK Slip Resistance Group (UKSRG) **Guidelines Issue 5** which is attached.

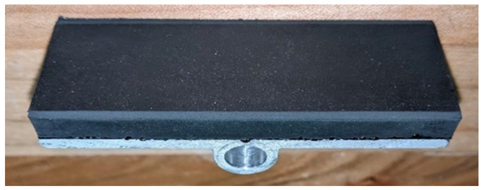
4.5.2. The next step in the **Task I Plan** for Task I-4b was Section 5.3: adaptation of an existing tribometer test method – in this case, the Pendulum test method generally common to the new "worldwide" standard EN 16165-2021, the former British BS 7976 standards (withdrawn when EN 16165 was published), Australian standards AS 4586 and AS 4663, and UKSRG Guidelines Issue 5. The adaptation of the Pendulum test method has been ongoing as RSs were developed; evolving challenges unique to testing 3D and porcelain/enamel surfaces were encountered, as were challenges with using Slider 55.

4.5.2.1. For all testing, TRRL rubber (also known as Slider 55) was chosen as the slider polymer. As it is softer than the Four-S rubber (Slider 96) more typically used with the Pendulum, and softer than the Neolite and other similar styrene-butadiene rubbers used for most other tribometers, it has advantages for conforming to 3D RSs and (importantly) for being less likely to damage the friction features on porcelain/enameled bathing surfaces. Such products typically instruct to clean only with non-abrasive cleaners and a sponge or cloth. Lastly, the UK Slip Resistance Group (UKSRG) Guideline Issue 5, the new "worldwide" standard EN 16165-2021, and Australian standards AS 4586 and AS 4663 cite the use of Slider 55 for testing surfaces used by barefoot people.

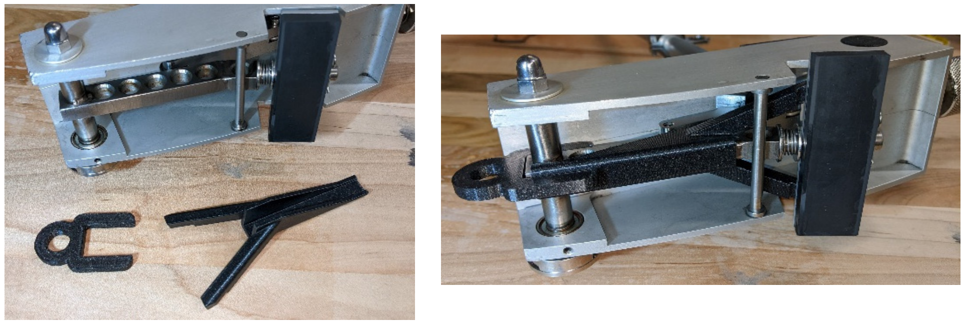
4.5.2.2. As described in the Pendulum methods listed above, slider conditioning (before testing) is typically done via multiple "swings" (common term for operating the Pendulum to traverse a test surface) across P400 grit sandpaper, a European grade which is similar to 320 grit US sandpaper. The P400 is done first and then multiple swings are done over 3M brand 3 micron lapping film, a superfine plastic-backed abrasive media that is pink in color; it is referred to in methods and publications as Pink Lapping Film or PLF. This pairing is commonly cited for Pendulum testing, though UKSRG Guidelines Issue 5 also discusses the use (for Slider 55) of 3M brand 30 micron lapping film, which is coarser though still superfine – it is green, so it is referred to as Green Lapping Film or GLF. Regardless, the abrasive conditioning puts a chamfer on the trailing edge of the slider; the chamfer is what contacts the test surface of interest. Methods generally limit this chamfer to no wider than 4mm [0.16"], while EN 16165 further limits the Slider 55 chamfer width to 2.5mm [0.10"]. Initial (December 2021) testing of Slider 55 in accordance with these methods revealed an intermittent problem with stick/slip resonant "chatter" oscillation of the slider about the longitudinal axis of its mounting pivot, when preparing the slider on both P400 and (as later discovered) GLF. On the P400, this chatter often results in a tapered and improper chamfer edge to the slider; the center is worn less than the edges, and the chamfer may exceed allowable width. See images below. On the GLF, this chatter causes an inflated measurement value – but the GLF is too fine to significantly damage the chamfer.

Chatter marks on P400 sandpaper used for Slider 55 conditioning

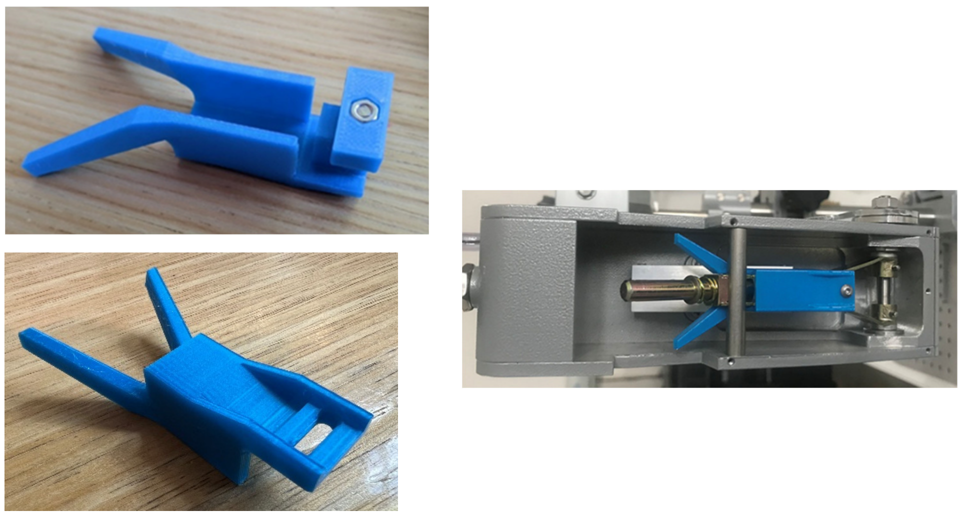

Tapered wear of Slider 55 chamfer due to chatter


Normal (untapered) chamfer on slider

Such oscillation, upon discussion with international Pendulum experts, is a less-known issue (most people use Slider 96 exclusively) that is not discussed in the aforementioned methods. It was represented by a UKSRG leader as being the reason for both Slider 55 and GLF having less acceptance in the technical community – because the oscillation led ultimately to results that were less consistent than those of Slider 96 and PLF. The use of GLF with Slider 55 was a point of some disagreement in UKSRG; when Guidelines Issue 5 was published in 2016 it was felt that PLF was too fine to abrade Slider 55 such that the chamfer would have a “fresh surface” for a new test session [as an aside, Forcon observed that PLF often didn’t freshen the Slider 55 surface, and switched to GLF in February of this year]. In UKSRG, it appears that the oscillation-related measurement inconsistency (the symptom, not the cause) reduced member interest in using GLF. Of interest is that UKSRG leaders did some work this year at reducing oscillation by placing rubber o-rings on either side of the slider bracket as dampers; the details were confidential until presented (as preliminary results) at IEA Slip & Fall 2022 in July. Regardless, their work was unknown to Forcon in December 2021 when the oscillation was first encountered. At that time Forcon began developing “conditioning clip” designs that now effectively stop this oscillation; they are 3D printed and the GCODE files are free for download. The clip has been presented before UKSRG, at Qualicer 2022 and at IEA Slip & Fall 2022 in the summer of 2022, with uniformly positive reviews. Forcon has proven clip designs for Wessex-style and Munro-style Pendulums. It took some time to get the Munro-style clips developed; Forcon doesn’t have a Munro Pendulum and had to rely on others and their schedules. See images below.



Wessex conditioning clip



Munro conditioning clip designs for screw and for Velcro strap

4.5.2.3. For new sliders EN 16165 specifies 20 swings across dry P400 grit sandpaper – and (as mentioned) it also specifies a maximum chamfer width for Slider 55 of 2.5mm [0.10”]. These simultaneous requirements are problematic for Slider 55, because project testing has revealed that even without oscillation, 20 swings of a new Slider 55 across P400 sandpaper may result in a chamfer of around 2.5mm; i.e., the conditioning of a new slider may wear it past the allowable limit. Forcon has confirmed this with Pendulum experts; the issue will be raised with the standards committee. Regardless, at about $100 plus shipping (from overseas), for each slider, testing would be impractically expensive. As well, the UKSRG, EN and AS methods previously discussed specify that prior to testing a different sample, a previously-used slider is to be reconditioned via 3 swings across P400 grit sandpaper. This is to remove grooving or damage caused by a more typical walkway material sample – but grooving and damage would not be expected on an embossed plastic or polymer composite bathing surface. Even the “grit” on the porcelain/enamel RSs in this project is much finer than the roughness of typical walkway materials. Because

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the testing of multiple samples (at 3 swings over P400 each) will quickly wear Slider 55 beyond the 2.5mm chamfer limit, this P400 refinishing has not been done. Given the microroughness of the RS materials, the Slider 55 reconditioning between samples (in this project) has been 10 swings across wet GLF. The 2.5mm chamfer limit has been observed for this project, though there is discussion within the Pendulum expert community that this 2.5mm limit is not based on a documented foundation. Summarizing, the method for this project will require conditioning clip usage when conditioning Slider 55 on P400 sandpaper and GLF. New Slider 55 sliders are conditioned via 10 swings on dry P400 followed by 10 swings on water-wet GLF (AS 4586 and 4663 specify 10 swings on P400 for new sliders). Used Slider 55 sliders are reconditioned by 10 swings on water-wet GLF.

4.5.2.4. Existing Pendulum methods use water as the contaminant. In initial project testing, the contaminant liquid was 0.05% sodium lauryl sulfate (SLS), a common solution that is used in ANSI/TCNA A326.3 as well as in the pending revision of human slip/tribometry validation standard ASTM F2508 which itself is based on human/tribometry testing at University of Southern California[1]. The benefit of SLS is that this surfactant helps to break the surface tension of the distilled water such that often-hydrophobic bathing surfaces can be coated with a thinner and more uniform layer of contaminant. Without the SLS, water beads up and significant areas of the RS will have basically no water on them unless a “pool” is created with perimeter walls. As of early February 2022, however, the concentration of SLS was changed to 0.1% due to the significant hydrophobic tendency of the porcelain/enamel pilot RSs. At 0.05% SLS significant contaminant beading-up was still present. Forcon deemed it prudent to select one concentration of SLS (0.1%) rather than introduce complexity through the use of different concentrations. SLS is not used as a contaminant during slider conditioning as it also acts as a lubricant.

4.5.2.5. One key step for Pendulum testing methods is the setting of the slider trajectory length (using a special “Perspex” gauge), which is ultimately setting the Pendulum arm’s pivot height above the top of the test surface. The testing of 3D surfaces brought the complication of setting the slider trajectory length on a discontinuous surface. The EN and AS standards somewhat gloss over this problem in their discussions of testing 3D profiled “tactile warning” walkway surfaces. A pattern of dispersed 3D friction features are indeed a discontinuous surface even if they are the same height and shape, and the height cannot be set properly using the normal method for the Pendulum. An alternative solution to this was developed by Forcon in December 2021 and reviewed with Pendulum experts. This “Shim Method” was

[1] M. G. Blanchette, J. Lee-Confer, J. R. Brault, B. Rutledge, B. S. Elkin, and G. P. Siegmund, “Human Slip Assessment of Candidate Reference Surfaces for Walkway Tribometer Validation: An Update to Standard ASTM F2508,” *Journal of Testing and Evaluation* https://doi.org/10.1520/JTE20210240

subsequently presented at UKSRG, at Qualicer 2022 and at IEA Slip & Fall 2022 in the summer of 2022, with uniformly positive reviews. The normal method for setting slider height can be viewed in **Section 2.5** of the Munro brand Pendulum instructions; these are provided for convenience, and the method is identical for other brands. The alternate procedure is as follows:

4.5.2.5.1. Creation of the shim pair

4.5.2.5.1.1. Obtain a ~rectangular piece of smooth, flat, rigid, uniform-thickness sheet material, e.g., sheet plastic or aluminum, 2mm [0.08”] thick or less, approximately 100mm x 150mm [4” x 6”] minimum. This will be referred to as the “slider shim”. Forcon uses 1mm [0.04”] aluminum.

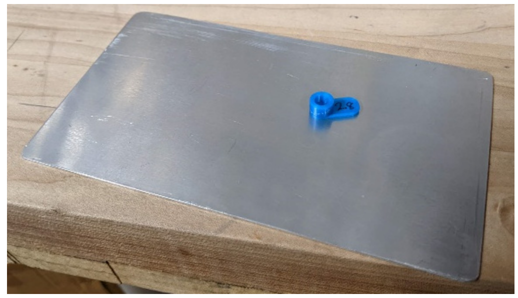
4.5.2.5.1.2. Verify that the gap between the slider lifting lever stop screw and the slider housing is no more than 0.4mm [0.016”]. Adjust as necessary and lock the screw with the locknut. Technically the Shim Method should work if this gap is greater than 0.4mm but the development of the method has been with less gap.

4.5.2.5.1.3. Ensure the Pendulum is properly leveled on a level surface. Using the Pendulum slider designated for the test session, set the slider trajectory normally using the Perspex gauge, as described in Section 2.5 of the Munro instructions (or equivalent) on a level smooth flat rigid “base” surface such as a float glass tile. Raise and lock the Pendulum arm.

4.5.2.5.1.4. Place the slider shim atop the “base” surface in the area used to set the slider height.

4.5.2.5.1.5. Release and manually lower the Pendulum arm such that the slider contacts the slider shim.

4.5.2.5.1.6. *Do not adjust the Pendulum arm height during this step*. Using feeler gauges or other smooth, flat, rigid, uniform thickness sheet material, create the “lever shim” by inserting enough thickness of material between the slider lifting lever stop screw and the slider housing to raise the slider such that, when measured using the Perspex gauge, the trajectory is again the correct length. The location for the lever shim is shown in the photo above Section 2.5 in the Munro instructions, though that photo shows Munro’s “spacer” which is different than the lever shim. The lever shim will typically be at least 2 times thicker than the slider shim. Forcon has created a set of 8 thicknesses of lever shims that can be 3D printed (file available for free download); they are designed to stay in place around the slider lifting lever stop screw. See image.



Forcon's aluminum 1mm slider shim and 3D printed 2.8mm high lever shim

4.5.2.5.1.7. In summary, for a flat test surface of any particular height above the Pendulum standing surface, the Pendulum arm pivot height should be the same with or without the shim pair in place.

4.5.2.5.2. Shim method usage

4.5.2.5.2.1. To use the shim pair on a 3D profiled surface, place the slider shim on the 3D surface and install the lever shim under the slider lifting lever stop screw. Set the trajectory length using the Perspex scale resting on the top of the slider shim. Remove both shims and conduct friction testing.

4.5.3. Sections 5.4 and 5.5 of the **Task I Plan** pertains to the evaluation of concave/convex configurations of RSs; this has not been performed yet due to already-existing information obtained in published research[2] conducted by the author and Dr. Mark Blanchette. The paper is attached as a PDF. Briefly, that research showed that for a uniformly gritty 2D porcelain-enamel shower pan cutout, the Pendulum with Slider 55 was effective at accommodating concavity greater than would be associated with the maximum 4% allowable slope in an ASME A112.19.1/CSA B45.2-compliant bathtub. This evaluation was to be revisited once the first group of Prototype RSs (3D vacuum-formed) were designed, friction tested, fabricated and sent to ASU for pilot human testing. It was expected that the 3D embossed plastic and gelcoat/fiberglass RS patterned surfaces would have the most effect on measurements, and that this will be pattern-specific. As such, Forcon deemed it most efficient to evaluate the measurement effect of such concave/convex patterns once "threshold" patterns were identified through human testing (see the following section for a discussion of "threshold" RSs). However, only as of 9/7/2022 has there been sufficient human test data provided to identify a 3D RS (3D35, discussed below) that is in the "threshold" frictional ballpark. As of this writing there has not been time (since 9/7/2022) to create the slightly concave (224cm [88"] radius) rigid fiberglass-backed mounting of a vacuum-formed 3D35 panel, for testing. A supplement to this Task I report will be submitted once this fabrication and friction testing is completed.

[2] J. P. Leffler and M. G. Blanchette, "Effects of Bathing Surface Drainage Contouring on Tribometer Friction Testing," Journal of Testing and Evaluation: https://doi.org/10.1520/JTE20210551

4.5.3.1. "Threshold" RSs: A project goal key to the development of F462+ is the creation of RSs that represent a frictional "threshold" of slipping. The "threshold" RS for each of the four different RS types will be the one where some of the human subjects (that test that particular RS) have experienced low-velocity or short-distance slips but none have experienced high-velocity or long slips, nor have they experienced no slips at all. This determination is further subject to nuance because certain of the RSs have anisotropy, and may have more human-utilizable friction in one orientation than another.

4.5.4. Section 5.6 of the **Task I Plan** consisted of friction testing of the initial 3D vacuum-formed (embossed plastic) RS prototypes, to determine if the friction test method and candidate tribometer could meet specific criteria:

4.5.4.1. Criteria:

4.5.4.1.1. Criteria 1: friction value increases with increasing number of 3D features per slider trajectory (fixed feature height).

4.5.4.1.2. Criteria 2: friction value increases with increasing height of 3D features (fixed number of features per slider trajectory).

4.5.4.1.3. Criteria 3: friction value does not reach within 10% of limits of measurement capability of tribometer.

4.5.4.2. Discussion

4.5.4.2.1. As documented earlier in this project, 3D features are a challenge for reliable tribometry. The above criteria were reasonable at the start of this new science project (before the real work started) but in retrospect the criteria are oversimplistic. Unique challenges were found with respect to:

4.5.4.2.1.1. the vacuum-forming process

4.5.4.2.1.2. the effects of different 3D feature shapes

4.5.4.2.1.3. the effects of different 3D feature patterns

4.5.4.2.1.4. the effects of friction test trajectory orientation relative to the 3D feature pattern

4.5.4.2.1.5. the evolution of methodological changes necessary to more-reliable 3D testing: the conditioning clip, the shim method, and the switch to GLF

4.5.4.2.1.6. the need to focus this method-qualification subtask on RS designs that approach usefulness for human testing and standardization

4.5.4.2.2. Numerous designs (15 of the 24 3D designs tested) were tested prior to the Shim Method being devised; the inconsistency of measurements on these 15 drove the Shim Method's development. Of these 15, 13 were patterns tested "squarely" to the slider trajectory, with a consistent feature pattern period

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starting and ending at the ends of the Pendulum's 125mm [4.9"] long trajectory. For example, some patterns had a repeat period of 25mm, or 12.5mm. See **3D RS Images A**. It was eventually determined that testing only "squarely" oriented to the pattern was not reflective of human bathing surface use, and it also affected the friction test performance. This will be discussed further below.

4.5.4.2.3. As to the vacuum-forming process issues, one bathtub manufacturer (early in the project) provided sheets of the acrylic they use for bathing surface products. After 17 patterns of designs attempting to use this acrylic, it was decided that this bathtub material was unrealistically thick for this project. The provided acrylic was 2mm +/- 0.2mm [0.08" +/- 0.008"], which is the thickness needed to *end up* with a bathtub: in the factory, the stretching/thinning of the acrylic in forming the deep sidewalls of a bathtub make the actual floor thickness more like 1mm [0.04"], though it will vary by model and brand. The 2mm thick material when used in this project's much-smaller-scale forming process doesn't have the ability to closely follow the geometric contours of the vacuum forming patterns (which Forcon made using 3D printing). Consultation with the manufacturer and a job shop reveal that the impact-modified acrylic sheet used for bathtubs is not available thinner than the materials received (unless custom ordered). Based on this, later RS prototypes were made from 1mm polyethylene terephthalate glycol (PETG) plastic. Another improvement to the RS creation procedure was to build a high-vacuum apparatus that resulted in much better conformance of the sheet polymer to the 3D "mold" features. This apparatus was used to create the initial vacuum-formed RS prototypes sent to ASU in March 2022. Human testing and Pendulum testing, however, reflected that that the conformance of the 1mm PETG still did not result in sufficient 3D feature definition – nor in much measured friction (3D27 and 3D31 RSs). The most recent feature patterns (3D35 & 3D36) have utilized 0.5mm [0.02"] PETG sheet, high vacuum (24 inHg), and 3D "mold" patterns with additional venting channels to reduce areas that vacuum doesn't reach – all in an effort to get more measured friction, and hopefully fewer human slips. These latest designs also facilitate steeper side flanks to the 3D features; a more "vertical" surface should lead to greater mechanical interlocking of the human foot with the RS – just as a cleated hiking boot sole does with a soft walking surface. Human testing results dated 9/7/2022 reveal that design 3D35 performs well, and it friction tests at 15 PTV. As such, 3D35 appears to be a good "threshold" friction RS candidate.

4.5.4.2.3.1. Criteria 3 issues here include little friction-measurement differentiation between all but the latest patterns due to the lack of 3D feature definition. As well, the measurement

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values for all but the latest patterns are low (e.g., 10 on a scale of 150; the criteria would require >15), however in practice few walkway materials test at the upper end of the Pendulum's range. For example, P400 sandpaper is coarser than most all walkway products, yet it tests at "only" 115 PTV with Slider 55.

4.5.4.2.4. Study of the fatality data provided to the F15.03 committee by CPSC in November 2021 eventually led to a decision to evaluate all RSs at multiple angles of slider trajectory orientation, even though the Pendulum would be unable to test installed bathtub floors at multiple orientations. Because the CPSC fatality data had a significant number of decedents who apparently fell while in the tub, not entering or exiting, the off-axis friction of candidate 3D designs was deemed worth evaluating. As such, the effort was refocused on redesigning RSs such that they could be tested at multiple orientations; this functionally obsoleted numerous designs as initially vacuum-formed. See **3D RS Images A**. These early designs, in 2mm acrylic, generally provided little measured friction – though they were tested before the shim method, conditioning clip, and GLF were put into use.

4.5.4.2.5. The symmetry and period-consistency of 3D patterns becomes theoretically less interesting once multiple orientations are tested, because (for example) the symmetry and consistency at 0 degrees does not exist at 15 and 22.5 degrees. Testing was conducted on the later 3D patterns at multiple orientations, and using the Shim Method – see **3D RS Images B**. Symmetric designs were typically tested at 0, 15, 30, and 45 degree orientations. Asymmetric designs were typically tested at 0, 22.5, 45, 67.5, and 90 degree orientations.

4.5.4.2.6. Testing of many of the 3D patterns was captured on high-speed video (960 frames per second), see https://youtu.be/ooou7Vqc9-8 and https://youtu.be/bk0ZmDXuuVo and https://youtu.be/4M-t4w9WQnA. Video of several patterns shows that given the natural frequency of the spring-loaded slider (whatever that is), there are friction feature patterns where the bouncing of the slider results in the slider just skipping along the peak tips (attenuation due to destructive interference), and not really getting into the troughs like the human's foot would. Some patterns result in the slider skipping entire rows of features. Whether this causes significant resonance or attenuation, it cannot be considered a desirable situation; consultation with Pendulum experts in the UK Slip Resistance Group supported this. As such, 3D RS designs provided to ASU were focused on 1] more-concentrated patterns (3D31, 3D35) that have a short enough period between rows of 3D features that resonance doesn't visibly occur, and 2] less-concentrated patterns oriented at a bias angle to the Pendulum trajectory (3D27). It is possible that reliable field testing of less-concentrated patterns (in future bathtubs) will depend upon the eventual F462+ standard prescribing a pattern bias angle for bathtub/shower products. This is not a preferable scenario but as always Forcon's goal is to minimize the specificity of such prescriptions; nevertheless, the peculiarities of friction testing are what they are.

4.5.4.2.6.1. Criteria 1 & 2 issues here, for certain 3D patterns and test orientations, are the resonance/attenuation's effect on measurements, potentially masking the Pendulum differentiation of patterns relative to their feature height or period alone.

4.5.4.2.7. The foregoing discussion pertains to the resonance of the slider as the slider carriage pivots about its lateral axis; an additional factor studied is the rotation of the slider about its longitudinal axis (mentioned earlier in the discussion of the conditioning clip). Comparative testing was done to see if constraining that slider motion was necessary; see https://www.youtube.com/watch?v=0dDbiSkaLLU. This testing utilized a complex and rigid custom-machined aluminum bracket which is not as readily usable (or nearly as cheap) as the conditioning clip described earlier – but the conditioning clip isn't rigid enough to eliminate all rotation. Despite how the YouTube video may appear, there was at most a 3 PTV difference in measurements between unconstrained resonance and constrained non-resonant motion, and this difference was typically less. Of course, more significant differences may exist for patterns other than the limited ones evaluated. Nevertheless, Forcon considers the rigid aluminum bracket not sufficiently beneficial to justify its expense and cumbersomeness. There may be benefits to further exploration of using the conditioning clip to reduce rotation of the slider across coarse patterns, but the clip does add mass to the pendulum arm – 8 to 13g [0.3 to 0.46oz] depending upon version – so that could affect measurements. The calibration of a Pendulum includes an allowable mass range for the arm, so if a particular unit's arm mass is at the upper end of the range, a conditioning clip could push it over the edge. Similarly there is an allowable range (in calibration) for the balance point along the arm, and a clip would change the balance point. The use of the clip for conditioning doesn't have these issues as measurements aren't being taken. It is worth noting that there are no other portable tribometer designs that are better at testing 3D features such as those studied here.

4.5.4.2.7.1. Criteria 1 & 2 issues here, for certain 3D patterns and test orientations, are the potential effect on measurement caused by longitudinal axis rotation of the slider,

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potentially masking the Pendulum differentiation of patterns relative to their feature height or period alone.

4.5.4.2.8. As the various 3D surfaces were developed, the ability to meet the above criteria was also dependent on resolving the issues that led to the two milestones of Forcon's development of the conditioning clip and shim method. There was also the milestone of changing to green lapping film from the finer pink (discussed earlier); the change affected the Slider 55 chamfer finish and measurements. Given the other project time demands and schedule, there has not been the time to redo all previous testing upon passing each of these milestones.

4.5.4.2.8.1. Criteria 1 & 2 issues here include that many RS designs were eliminated as candidates before the three milestones happened – though based on the foregoing discussion about vacuum forming processes, this was likely not a significant loss. Nevertheless, decisions made about whether the criteria were satisfied were somewhat obsoleted by subsequent passing of the milestones. Criteria 3 issues are that the change to GLF would be expected to increase PTV values slightly.

4.5.4.2.9. As discussed at length in Forcon's Terms of Subcontractor Bid, the whole topic of 3D RS design is challenging in that there are few restrictions on what 3D feature shapes and patterns a bathing surface manufacturer may choose to produce. Forcon has modeled 34 different 3D vacuum-formed designs and tested most all of them. Each tested one differs by 3D feature shape, height, and pattern – and the plastic sheet thickness used for forming. The work it takes to produce these RSs is significant – the design is modeled in CAD, 3D printed in a ~150mm [6"] prototype size for friction testing, vacuum formed, trimmed, a board is cut, the plastic is mounted to the board, the board is caulked and painted, and the prototype is friction tested. Importantly, the friction measurement at this stage is of somewhat academic interest – because it is unknown whether humans will be likely to slip on it. Because of the effort it takes to produce a good vacuum-formed RS candidate, the decisions about whether to take the time to repeat the fabrication process (on a more time-consuming larger scale) to produce an RS-size version should be an informed guess based on human testing results. "Complete" human test data was first received on July 30, 2022; video confirmation sufficient to make well-founded decisions on 3D RS design choices has remained elusive. Another factor is that merely producing lots of different 3D vacuum formed RS designs and "throwing them over the wall" for human testing would bog down the human testing resources without tangible benefit.

4.5.4.3. In summary, based on the following helpful & unhelpful elements, Forcon believes that the subject criteria could be satisfied for certain "families" of 3D feature shape/pattern combinations. Other families of 3D shape/pattern combinations may not meet the criteria.

4.5.4.3.1. methodological improvements to friction testing processes

4.5.4.3.2. improvements in vacuum-formed 3D feature definition

4.5.4.3.3. the virtually unlimited 3D feature designs and patterns that could be produced

4.5.4.3.4. the effects on tribometry of different 3D feature shapes

4.5.4.3.5. the effects on tribometry of different 3D feature patterns

4.5.4.3.6. the effects of friction test trajectory orientation relative to the 3D feature pattern

4.6. Task I-4c: Plan for evaluating tribometry procedure repeatability and reproducibility.

4.6.1. The **Task I Plan** section 6 specified that interlaboratory studies (ILSs) would be run on early RS prototypes; an ILS is an evaluation of the method more than the material tested. Certain RS candidate designs were to be sent out for an ILS by mid-February 2022, to Australia (Safe Environments Pty Ltd.) and California (Jim Flynn, PE). However, the Slider 55 issues and necessary development of the conditioning clip, until recently available only for the Wessex, affected the timing of such testing, as did the switch from PLF to GLF. It was deemed disadvantageous to send the RSs out for an ILS when the procedures and apparatus were still being refined. As well, running an ILS on RSs that haven't been shown to be good candidates for approaching the frictional threshold (as determined by human testing) seemed a questionable use of the limited ILS resources – and only in recent weeks has adequate information on vacuum-formed RS vs. human performance been available. As of this writing ILS shipments have been sent to Safe Environments Pty and Jim Flynn; these contain a 3D35 150mm [6"] prototype, conditioning clips, shim pairs, SLS, GLF, new Slider 55 sliders, and instructions. See **ILSnotes083122.pdf**. Upon completion of the ILS for 3D35, a supplement to this Task I report will be submitted. It was decided to not send 2D porcelain-enamel RS samples for ILS as it is the 3D method particulars that are new and unique, and because the 2D RS samples used in this project to date are not actually RS candidates, as they are simply production bathtub bottom cutouts. This is due to the lack of cooperation from any porcelain-enamel bathing surface manufacturer in creating generic and non-proprietary RS candidates. It was decided not to send the "3DF" simulated 3D gelcoat/fiberglass RSs for ILS as they are epoxy-coated 3D printed patterns, not actual gelcoat/fiberglass. An actual gelcoat/fiberglass RS (3DF08) has been produced recently; its production was back-burnered due to delays in getting human test data. A 150mm prototype could be produced of 3DF08 if human testing shows that it is a good frictional-threshold RS candidate; the gelcoat/fiberglass fabrication process involves many high-VOC toxic solvents and as such the fabrication of any such surface should be only when justified. A thorough discussion of the production of these RSs will be in the upcoming Task II report.

4.7. Task I-4d: Requirements for RS usage as verification surfaces to calibrate and validate tribometers.

4.7.1. See **Task I Plan** section 7. This is not a task that can be performed as part of this project as it requires production RS manufacturer involvement.

4.8. Task I-5a: Not quoted.

4.9. Task I-5b: Not quoted.

4.10. Task I-5c: Accommodate human testing needs for project through design of bathtub/shower mockup

4.10.1. Generally ASU developed the test apparatus design independently of Forcon. Shared characteristics include the following:

4.10.1.1. RS surfaces are 457mm (18 inches) square. If the friction surface covers less than these dimensions, the surface is centered within the square. Reference surfaces have a base of 19mm (0.75 inch) thick medium density fiberboard (MDF) to which the friction surface is bonded using thermoset putty similar to auto body filler (e.g., Bondo) or epoxy. The thicker mosaic RSs are bonded to 12mm (0.47 inch) MDF. The MDF is sealed (after bonding) using water-resistant paint, though the RSs are not designed to be submerged during testing at ASU.

4.10.1.2. The RSs are sloped at a 4% (2.3 degree) angle representative of the allowable maximum drainage slope in bathing surface standards. It is sloped down away from the bather at the point of bathing surface entrance.

5. Conclusions

5.1. This unique project explored many new complexities involving the already-complex topic of friction testing. The testing of 3D-profiled and patterned surfaces (in particular) was a topic only superficially discussed in walkway tribometry research and standards, and as the project progressed it became apparent that new methods and tools were needed. The road to reliability in tribometry is a long one even without testing 3D surfaces, and Forcon’s methods incorporate current best practices – in a field in which greater reliability is always being sought.

5.2. The almost-total lack of cooperation from bathing surface manufacturers regarding technologies and methods was the key driver to the eventual set of reference surfaces that Forcon produced. The types of surfaces used for actual bathing surfaces have production complexities that do not necessarily translate directly to small-scale production – though such discussions are more within the scope of Task II than Task I. An efficient dialing-in of the reference surface designs, with respect to having surfaces that represent “threshold” friction, would have relied on more timely availability of relevant human test data.

5.3. The time needed to develop and prove-out the conditioning clip & shim method, combined with human testing project and data delays, combined with the lead time

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necessary to design and produce new reference surface candidates, all complicated the ability to meet elements of the original Task I Plan (which was written before this new and unique project's work began).

5.4. Forcon believes that the new methods/tools developed and certain reference surface candidates provide a sound foundation for both future human testing and the eventual creation of a replacement for ASTM F462. This is significant, given the complexity of this scientific topic. Other reference surfaces produced as part of this project, specifically the porcelain-enamel surfaces, are of some benefit to the human testing but not to replacing F462 – because of the lack of manufacturer/supplier support in this specialized technology.

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CPSC PROJECT 61320621Q0068

TASK I-1 REPORT

"The contractor must conduct a comprehensive review of ASTM F462 Standard Consumer Safety Specification for Slip-Resistant Bathing Facilities and other applicable industry and international standards related to adult bathing surface slip resistance."

LITERATURE REVIEW

1. ASTM F462:1979(R2007), withdrawn 2016. Standard consumer safety specification for slip-resistant bathing facilities. West Conshohocken, PA; ASTM International.

   1.1. This standard specifies a tribometer test method for friction testing of bathing surfaces, with a pass/fail criterion of 0.04 SCOF. The criterion is to be met while the bathing surface is under its manufacturer "guarantee". There is no requirement for tribometer performance verification, and the standard could not be approved now as there is no precision statement (as has been required for ASTM test methods for years).

   1.2. Per the introduction to this standard, it was developed in response to CPSC-funded research: ABT Associates, Inc., June 4, 1975. Contract # CPSC-P-74-334, A Systematic Program to Reduce the Incidence and Severity of Bathtub and Shower Area Injuries.

      1.2.1. This research report analyzed CPSC NEISS data and filtered out 255 incidents which were investigated to a greater depth than typical NEISS-recorded incidents; these were subsequently grouped into 17 scenarios. Scenarios 6, 10, 11, and 12 involved bathing surface friction-related slip events. At the time of the study, it was not uncommon for bathing surfaces to have no friction features per se, and the ages and origins of bathing surfaces involved in the incidents were not known.

      1.2.2. Key findings from the research include the following:

         1.2.2.1. Slip events were the most common bathing surface incident.

         1.2.2.2. Bathtub slip events were more prevalent than shower slip events.

         1.2.2.3. Children under age 10 have the most incidents and the most fatalities.

         1.2.2.4. Elderly people tend to have more severe injuries.

      1.2.3. Key conclusions reached by the authors include the following:

         1.2.3.1. "Every tub and shower stall will be provided with a standing surface which is non-skid."

         1.2.3.2. "Definitions of non-skid are required."

         1.2.3.3. "Determination of the parameters of movement associated with accident sequences is required."

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1.2.3.4. "A means of establishing the level of slip resistance is required and might be accomplished by evaluating all available slip testers."

1.2.3.5. "The test chosen must accurately simulate the wet foot and the extremes of bathing activity, as well as the conditions present in typical accident sequences, such as partially filled tubs, wet tubs, and soapy films."

1.2.4. Discussion: The conclusions reached by the authors were laudable, though the means to achieve those goals were apparently beyond the state of knowledge and rigor of practice that existed in the 1970s. The instant project, in 2021-2022, will generally meet most of these 1975 goals.

1.3. The development of ASTM F462 was described in the following paper: Brungraber RJ, Adler SC. Technical support for a slip-resistance standard. In: Anderson C, Senne J editors. Walkway surfaces: measurement of slip resistance, ASTM Special Technical Publication 649. Philadelphia; American Society for Testing and Materials: 1978.

1.3.1. This 1978 ASTM paper documents certain elements of the CPSC-funded research intended to result in a tribometry standard for bathing surfaces; the research was led by Robert Brungraber, PhD, PE. The paper discusses the choices for a tribometer, a frictional slider material, a contaminant, and a test method. It also discusses how a pass-fail criterion was developed.

1.3.2. The tribometers considered were a dragsled (Horizontal Pull Slipmeter), two pendulums (Sigler and British Pendulum), two articulated strut devices (James Machine and NBS-Brungraber Mark I), and the Kollsman tester. The HPS was eliminated because of its small slider size. The pendulums were eliminated because the velocity of the slider during contact was much faster than a human foot slipping. The James Machine was not suited for testing bathing surfaces in-situ. The NBS-Brungraber Mark I was chosen over the Kollsman because the Mark I was more portable and convenient, and because it "could be calibrated against a reliable standard over the entire range that it is going to be expected to evaluate". At the time the method was developed, there were a total of two NBS-Brungraber Mark I tribometers in existence; it was invented in 1975-1976.

1.3.2.1. Discussion: Per Leffler/Blanchette[1], the Mark I tribometer (despite nearly 200 being produced over an 18-year span) never underwent an InterLaboratory Study (ILS) to determine the reproducibility of measurements; as such, a Mark I user cannot know how their measurements statistically compare to other users with other Mark I tribometers, or to the 0.04 SCOF threshold in F462. The Mark I tribometer design drawings had few dimension tolerances and incoming parts (the Mark I was built by Robert Brungraber) typically did not undergo dimensional quality checks; as such, each device may be significantly different in execution. The Mark I features two sets of long parallel shafts which introduce systematic frictional variability, and the

[1] Leffler JP, Blanchette MS. Forensic considerations regarding traction and tribometry of bathing surfaces. Journal of the National Academy of Forensic Engineers, Volume 33, No. 1, June 2016, 37-45.

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measurement recording components are delicate and easily damaged; both of these issues can affect measurement values – but as mentioned, no ILS was ever done to evaluate the effect of these issues

1.3.3. The Brungraber/Adler paper discusses that the selection of slider material had as a goal that "it should represent, if possible, the skin on the bottom of the human foot." Numerous materials were evaluated, including (based on discussions with Dr. Brungraber) a material called "slunk", which is the skin of an unborn cow. Time constraints precluded an extensive study, and Dow Corning Silastic 382 was selected, which is a breast implant polymer with a durometer of approximately Shore 46A.

1.3.3.1. Discussion: Per Leffler/Blanchette[1], the Dow Corning Silastic 382 slider polymer was discontinued after Dow Corning was sued in the 1990s; this breast implant polymer was blamed for medical injuries in persons with implants. No other polymer manufacturer made an alternate polymer reliably known to be equivalent.

1.3.4. The Brungraber/Adler paper discusses that the selection of a contaminant included "a series of disappointing but enlightening tests" on various soaps; eventually it was decided to use a 1:4 ratio of soap to water, with the soap being one that is compliant with Federal Standard PS-624g or ASTM D799. The test method specified that testing would be conducted in multiple locations on a bathing surface, with the tribometer in an 0.5-1.5" deep pool of the contaminant.

1.3.4.1. Discussion: Per Leffler/Blanchette[1], the contaminant pool of 0.5-1.5" of high-concentration soap solution would be expected to affect measurements as the Mark I slider and lower end components needed to move within this fluid resistance. There were no studies done regarding whether different soap formulations (that met the specified Federal and ASTM standards) would affect measurements. The Brungraber/Adler paper does not detail why such a high concentration of soap was used, versus one more representative of actual bathing by humans. The ASTM soap standard cited in F462 was withdrawn in 2000.

1.3.5. The Brungraber/Adler paper discusses that the F462 pass/fail criterion was based on comparative testing of fifty different production bathing surface samples, representing different materials and manufacturing processes, and many of which had no friction features. These samples were tested with one of the two existing Mark I tribometers. The criterion was that the static COF was to be twice the *highest* COF among the samples with *no* friction features, which was also twice the *lowest* COF among the samples *with* friction features. This resulted in the criterion being a SCOF of 0.04.

1.3.5.1. Discussion: Per Leffler/Blanchette[1], the friction threshold of 0.04 SCOF had no correlation to human slips or human frictional requirements. It was based on comparative testing of 50 bathing surface materials against each other, not against what humans need for friction. The friction threshold of 0.04 SCOF represented a value only 2-3% above the minimum friction the Mark I can measure: it is so low it is barely measurable. As such, the choice of twice the SCOF of the best untextured bathing surface (in the 50-surface research) was not well-founded. This is compounded by the absence of reproducibility statistics.

1.3.6. The Brungraber/Adler paper discusses that a calibration curve for the Mark I was developed using known loads and forces. It also discusses that "standard reference surfaces" were being sought that represented a wide variety of friction levels.

1.3.6.1. Discussion: No array of reference surfaces was ever developed for evaluating Mark I performance across different friction levels; only a glass reference surface (effectively zero friction) is cited.

1.3.6.2. Discussion: No periodic calibration of the Mark I was required by ASTM F462. The units currently in use (in 2021) by bathing surface manufacturers have not received service or calibration in at least 11 years, as Robert Brungraber retired in 2010.

1.4. ASTM F462 was unchanged across numerous reapprovals, the final reapproval in 2007. It failed reapproval in 2016 and was withdrawn; the F15.03 committee at the time did not overcome negative votes regarding the proposed replacement slider polymer and soap, and the lack of documentation of the equivalence of these materials to those originally cited in F462.

2. ANSI/ASME A112.19.1:1979. Enameled cast iron plumbing fixtures. New York, NY; American Society of Mechanical Engineers.

2.1. This ASME standard, and its many subsequent revisions, cite ASTM F462 for "slip resistance" determination without modification. These are referenced by the U.S. government (e.g., 24 CFR 3280.604 for Manufactured Housing) and (since 2000) by the International Plumbing Code. The 1984 revision of ANSI/ASME A112.19.4 *Porcelain Enameled Formed Steel Plumbing Fixtures* also referenced F462 but was merged into the 2008 revision of A112.19.1, which is now a standard harmonized with the Canadian Standards Association, designated as CSA B45.2. Current revisions of these standards continue to cite ASTM F462 despite F462 being withdrawn in 2016.

3. IAPMO/ANSI Z124.8:2013. Plastic liners for bathtubs and shower receptors. Ontario, CA; International Association of Plumbing and Mechanical Officials.

3.1. This standard is for the manufacture of sheet plastic liners intended for use in retrofitting existing porcelain-enamel (and other) bathing surfaces. The liner's friction replaces that of the original bathing surface.

3.2. This standard adopts ASTM F462 without modification.

4. BS 8445:2012. Bath and shower mats – Testing – Assessment of slip resistance properties. London, BSI Group.

4.1. This standard is for the testing of bathtub/shower mats by barefoot human subjects utilizing a ramp test. In ramp testing, the human subject has a fall harness as backup while they walk forward and backward on the test surface at increasing angles of test surface angle from the horizontal.

4.2. This standard is not for bathing surfaces per se, it is for products placed on bathing surfaces, in effect replacing the friction features of the bathing surface.

4.3. Discussion: Issues with this ramp testing include:

4.3.1. The "calibration boards" that test subjects are supposed to walk on and obtain specific values; these can be difficult to obtain and of limited durability.

4.3.2. The general expectation and anticipation by the human subject that they may be about to slip, causing them to modify their gait.

4.3.3. The unnatural character of walking backward.

4.3.4. The specific potential for a higher and non-representative level of care to be taken by test subjects as they may be concerned that their unshielded toes may suffer injury against the ramp apparatus in a slip.

4.3.5. Potential fatigue and/or bias of the human subject.

5. SA HB 198:2014. Guide to the specification and testing of slip resistance of pedestrian surfaces. Sydney; Standards Australia.

5.1. This handbook discusses different pedestrian environments and provides friction level recommendations for both British Pendulum tribometers in water-wet testing and inclined ramp testing with oil-wet surfaces.

5.2. The recommendations include friction levels for swimming pool ramps, shower rooms, and changing rooms. However, enquiries to one of the primary authors of this handbook revealed that the friction levels were determined for pedestrians wearing shoes, and not barefoot.

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CPSC PROJECT 61320621Q0068

TASK I-2 REPORT
November 17, 2021

"The contractor must conduct a comprehensive review of related standards such as industry and international standards for flooring slip-resistance requirements."

LITERATURE REVIEW

Comments: This review pertains to wet friction test methods in current standards for flooring, and friction threshold values where cited in those standards.

1. ANSI/TCNA A137.1:2021. Specifications for Ceramic Tile. Anderson, SC; Tile Council of North America.
   - *1.1.* Scope: *These Specifications describe the normally available sizes and shapes of ceramic tile: the physical properties of Standard Grade and Second Grade Ceramic Tile, Decorative Tile and Specialty Tile; the basis for acceptance and methods of testing prior to installation; the marking and certification of ceramic tile; and the definitions of terms employed in these specifications.*
   - 1.2. This is a general standard for the manufacture of ceramic and clay tile. It covers dimensional tolerances, warpage, water absorption, stain resistance, and many other factors, in addition to Dynamic Coefficient of Friction (DCOF). For evaluating different areas of tile performance in the standard, a passing criterion is established which is to be tested (in nearly every example) relying on another standard as the method for verification. In the case of DCOF, a value of 0.42 is to be met "for level interior surfaces expected to be walked upon wet", for mosaic tile, quarry tile, pressed floor tile, and porcelain tile. The DCOF is to be determined using the test method ANSI/TCNA A326.3, discussed below.
2. ANSI/TCNA A326.3:2017. Test Method for Measuring Dynamic Coefficient of Friction of Hard Surface Flooring Materials. Anderson, SC; Tile Council of North America.
   - 2.1. Scope: *This standard describes the test method for measuring dynamic coefficient of friction (DCOF) of hard surface flooring materials. This method can be used in the laboratory or in the field.*
   - 2.2. The core test method in this standard is from earlier (than 2017) versions of ANSI/TCNA A137.1; it was moved out of A137.1 into its own standard.
   - 2.3. The standard establishes that a DCOF value of 0.42 is to be achieved for wet hard surface flooring materials that are suitable for level interior spaces. The testing is to be conducted using the BOT-3000E tribometer, a motorized dragsled manufactured by Regan Scientific Instruments. The standard does not define "hard surface flooring". It has many advisory caveats as to relying upon the 0.42 DCOF value.
   - 2.4. The BOT-3000E tribometer uses a 28mm wide slider with a transverse contact radius of 75mm; the effective length of contact is about 3mm. The slider polymer specified for the standard is styrene butadiene rubber (SBR), Shore 95A durometer,

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which appears to be Neolite (Smithers-Rapra). The device can be set for different travel trajectory lengths but 254mm is the length used for the standard. The device travels a short distance upon actuation and then records DCOF data until the trajectory ends, at which point the device stops. The output shows a graph of the DCOF across the trajectory, which is averaged, and the minimum and maximum DCOF are documented.

2.5. This standard specifies a slider sanding fixture (utilizing 400 grit sandpaper strips), a validation weight, and a verification surface for use before testing. The verification surface is a flexible (and typically warped) piece of high-pressure laminate (similar to "Formica").

2.6. Section 11.2 of the A326.3 standard cites InterLaboratory Study (ILS) data for repeatability and reproducibility (R&R) for 7 different ceramic tile surfaces. The ILS was conducted before 2012 using the BOT-3000 (not the BOT-3000E); there are no details provided in the standard about the specific surfaces tested, and none of these surfaces is claimed to relate to the 0.42 DCOF friction threshold in the standard. The R&R for the 7 different surfaces expectably differs.

2.7. One advisory caveat is that "no claim of correlation to actual footwear or human ambulation is made". Other materials published by TCNA[1] state that the 0.42 value is based on a 1995 doctoral thesis by Stefan Bonig in Germany, from his research involving utilized COF (uCOF) testing with humans (not tribometry). The TCNA justification then cites a study by Jens Sebald[2] that in part correlates the BOT-3000 (an earlier version of the BOT-3000E) to German ramp testing (using human subjects), though Bonig did not use ramp testing.

2.7.1. About the BOT-3000 Sebald stated the following:

2.7.1.1. "Deficits in simulation of the human walk"

2.7.1.2. "Floor coverings and sliders the profiles of which intermesh may give rise to false values"

2.7.1.3. "At high slip-resistance values, the driven wheels tend to spin"

2.8. Discussion:

2.8.1. Relative to this CPSC project, no tribometer has been shown to reliably "simulate the human walk", though it is a commonly asserted deficiency, or in the case of tribometer sellers claiming biofidelity, an unlikely proficiency. Chang[3] discusses the complexity of friction mechanisms; adhesion, hysteresis, and damping will all differ significantly from machine-applied forces to human-applied forces. A portable tribometer may approach one element of biofidelity (e.g., heel contact velocity), but the organic variability of human joints will always introduce many more variables to the equation – variables that affect (for example) adhesion, hysteresis, and damping. As such, it is an

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1 https://www.tcnatile.com/images/pdfs/Rsch_suptng_ANSI_std_slip_resist_TCNA_TI_Mar-2016.pdf
2 Sebald J. System Oriented Concept for Testing and Assessment of the Slip Resistance of Safety, Protective, and Occupational Footwear. Berlin: Pro Business GmbH, 2009.
3 Chang WR et al. The role of friction in the measurement of slipperiness, Part 1: Friction mechanisms and definition of test conditions. Ergonomics 2001, Vol. 44, No. 13, 1217-1232.

unachievable goal to pursue biofidelic means of tribometry when the potential exists for statistical correlation of human slip testing to tribometer testing.

2.8.2. Given the foundations for the 0.42 DCOF value in A326.3, it is worth discussing published standards that base target friction values on experiential data, as that has been another foundation asserted by ANSI ASC108 (the TCNA ANSI committee) leaders in conversation. Again with A326.3, there is no human-derived correlation of the standard's BOT-3000E tribometer to its target friction value; arguably this is a technical deficiency in the standard, but ASC108, largely composed of flooring manufacturers and installers, considers this value defensible (at least in part) because of feedback these committee members get from their respective customers. This feedback, likely experiential data, is apparently not disclosed. For the limited, almost "internal" purposes of a specific industry's standard, self-regulation perhaps, experiential data may be a justifiable foundation. However, if such a methodology starts to undergo a broadening of its scope (e.g., from ceramic tile to "hard surface flooring") without a broadening of its technical foundations, then it might be time to challenge the reliance on experiential data.[4]

2.8.3. The BOT-3000E graph output is useful in demonstrating an issue with the device: testing over grout joints and other large surface discontinuities causes spikes in the DCOF measurement – which is nevertheless averaged into the run's test result. It is possible, depending upon the geometry of the discontinuity, to have the spike bias higher or lower in DCOF, which raises (or lowers) the average measurement. In this scenario, a surface could be below a "passing" DCOF of 0.42 except for a couple spikes that raise it above 0.42. This biasing, regardless of direction, is not necessarily indicative of an actual pedestrian-relevant increase or decrease in friction, so it is a deficiency in the tribometer. This is even though (to date) manufacturers of certain ceramic tile styles available in both mosaic and non-mosaic versions have stated that a surface isn't recommended for wet walkways unless it is the mosaic – perhaps because higher BOT values have resulted from the grout joint spikes. Versions of A326.3 in development appear to alert readers of the issue; the IAPMO Uniform Swimming Pool, Spa, and Hot Tub Code (2021) is explicit in precluding the use of the BOT-3000E over grout joints and 3D features.

3. BS 7976-2:2002+A1:2013. Pendulum testers – Part 2: Method of operation. London; BSI Standards Limited, https://doi.org/10.3403/02629790U

3.1. Scope: *This part of BS 7976 specifies a method of operation of the pendulum tester specified in BS 7976-1. It is applicable only for use in determining the slip resistance of pedestrian surfaces. This standard does not apply to the specific procedures for road and airfield surfaces in BS EN 13036-4, or to the use of the pendulum test as described in current product standards*.

3.2. This standard is the second of three BS 7976 standards for the British Pendulum. The BS 7976-1 standard is the specification of Pendulum characteristics, that theoretically would allow the reader to build their own tribometer, while the BS 7976-

[4] Excerpted in part, with modification, from Leffler JP, Competence and complexity in the changing world of slip-and-fall analysis. Georgia Defense Lawyer, Fall 2021.

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3 standard is for calibration of the device. The BS 7976-2 standard describes how to validate and prepare the Pendulum and then how to test with it.

3.3. It is stated in the Foreword that European CEN Technical Specification 16165, if it is published as a standard (instead of a Technical Specification), might supersede BS 7976-2. CEN/TS 16165 is described below; it reportedly will be published as a full standard, DIN EN 16165, in December 2021.

3.4. The method accommodates “TRL” rubber sliders (known as Slider 55 in other standards) and “Four-S” sliders (known as Slider 96 in other standards); there is a temperature correction to be used with TRL sliders.

3.5. The slider dimensions are 76mm wide x 25mm long. The slider is spring loaded and angled up 26 degrees from the horizontal, and the length of the contact trajectory is 125mm. The trailing edge of the 76mm wide face first encounters the test surface.

3.6. The method specifies two slider conditioning materials: P400 sandpaper (similar to US 320 grit sandpaper), and 3M 3-micron lapping film, an ultrafine pink-color sandpaper used for polishing optical fibers (often referred to as PLF for pink lapping film). The method includes an optional verification procedure, referencing friction value ranges for a “float glass” surface and for the lapping film.

3.7. The Pendulum is stated as measuring PTV (Pendulum Test Value); the standard does not mention coefficient of friction.

3.8. Discussion: The Pendulum is often referred to as a DCOF tester. Consistent with Chang[3], however, DCOF measurements are to be evaluated under steady-state conditions, i.e., at a constant sliding velocity, because the velocity can affect measurement values. The Pendulum slider, in contrast, obtains its measurements based on the friction-caused deceleration of the slider while in contact with the surface; this is not DCOF, it is energy dissipation.

4. DIN 51131:2014. Testing of floor coverings - Determination of the anti-slip property - Method for measurement of the sliding friction coefficient. Berlin; Beuth Verlag GmbH, https://dx.doi.org/10.31030/2078107

4.1. Scope: *This standard specifies the parameters for measurement of the sliding friction coefficient on surfaces usually walked on with footwear. It applies for the measurement of floor coverings with or without displacement space up to 4 cm^3/dm^2 and for textile floor coverings. The measurement can be carried out on dry, wet surfaces or on surfaces with defined lubricant as well during operation.*

4.2. This standard is not available in English language. It is stated on the DIN website that this standard will be replaced by DIN EN 16165 when it is published as a standard (see below for information on CEN Technical Specification 16165).

4.3. This standard is for the use of a motorized dragsled design that has specifications within the standard for the user to create their own device, though the GMG-200 tribometer made by GTE Industrieelektronik GmbH (Viersen, Germany) is typically utilized. With this device, a cable is deployed and anchored along the surface, and the tribometer travels by reeling in the cable.

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4.4. The standard specifies a triad of sliders which each are rectangular, 10mm wide and 37.5mm long, with a 45-degree leading edge chamfer. The three 10mm wide chamfered edges first encounter the test surface. The travel trajectory is 500mm.

4.5. Sliders for wet testing are SBR, Shore 60D. Slider prep uses 120 grit and 320 grit sandpaper. There are three verification surfaces that can be used.

4.6. Discussion: The GMG-200 is rarely seen in the US. One deficiency relative to this project is that the travel trajectory is half a meter; many changes in bathing surface topography could occur in 500mm, which could affect measurements. Another deficiency is the fact that the standard is not available in English, nor is a translation (official or not) available.

5. AS 4586:2013. Slip resistance classification of new pedestrian surface materials. Sydney; Standards Australia.

5.1. Scope: *This Standard provides means of classifying pedestrian surface materials according to their frictional characteristics when determined in accordance with the test methods set out in Appendices A, B, C, D, and E. The test methods enable characteristics of surface materials to be determined in either wet or dry conditions. This Standard does not provide for the conditioning of specimens to account for in-service wear.*

5.2. This standard is for friction testing using both the British Pendulum and the “Floor Friction Tester”, which is generically described in the standard, but the Tortus 3 (Wessex Precision Instruments) is typically used, though for dry testing only. See the description of the Pendulum above for BS 7976-2.

5.3. The standard refers to Pendulum measurements as “BPN”, or British Pendulum Number, which is the same as PTV in BS 7976.

5.4. The British Pendulum test method references BS 7976-3 for calibration.

5.5. Sliders and slider preparation are basically identical to BS 7976-2 except AS 4586 calls for ten wet slips on PLF rather than twenty, and BS 7976-2 does not call for PLF slips on Slider 55.

5.6. This standard has guidance for testing on 3D profiled surfaces; it suggests testing at a bias angle to 3D features and suggests testing in multiple orientations on patterned features. The lowest BPN values obtained are the ones to be cited in testing such surfaces.

5.7. The standard includes correction factors for testing on slopes. The standard includes “classifications” for friction measurement ranges, which are cited in SA HB 198 (described below). For example, Class P3 surfaces would test between 35-44 BPN with Slider 96 and 35-39 BPN with Slider 55.

5.8. Discussion: This standard and the similar AS 4663 (discussed below) are in effect expanded and more informative versions of BS 7976-2. The test procedure is virtually identical yet there is more information about applications and test surface characteristics.

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6. AS 4663:2013. Slip resistance measurement of existing pedestrian surfaces. Sydney; Standards Australia.
   6.1. Scope: *This Standard provides methods of measuring the frictional characteristics of existing pedestrian surfaces in wet and dry conditions.*
   6.2. This standard is basically identical to AS 4586 with regards to friction test procedures. It does have additional guidance on selecting areas of existing pedestrian surfaces to test, compared to AS 4586 which is for new surface materials.
7. SA Handbook 198:2014. Guide to the specification and testing of slip resistance of pedestrian surfaces. Sydney; Standards Australia.
   7.1. This handbook does not define a Scope.
   7.2. This handbook discusses different pedestrian environments and (among other things) provides friction level recommendations for British Pendulum tribometers in water-wet testing. It references AS 4586 and AS 4663 for the obtaining of friction measurements.
   7.3. The recommendations include friction classification values (see AS 4586 discussion) for ramps and stair nosings required to be slip resistant by the National Construction Code (of Australia). Recommendations are also included for the flooring of numerous types of commercial occupancies not required by the NCC to be slip resistant.
   7.4. Discussion: while not a test method, this handbook provides a fairly unprecedented level of modern guidance on friction levels. The level of knowledge that exists (external to the Handbook) regarding the reliability of the Pendulum provides a sound backup for this guidance, though it is true that any such guidance will be the subject of some debate. The Pendulum is bulky to transport; the large travel case all up weighs 300N (67lb), it takes at least 15 minutes of setup time to prepare for measurement, and it can be ergonomically marginal for the operator when used at ground level. But again, the available data on reliability (due to years of worldwide research) is unmatched for portable tribometers.
8. ASTM E303:1993R2018. Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester. West Conshohocken PA; ASTM International.
   8.1. Scope: *This test method covers the procedure for measuring surface frictional properties using the British pendulum skid resistance tester. A method for calibration of the tester is included in Annex A1. The British pendulum tester is a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface. The tester is suited for laboratory as well as field tests on flat surfaces, and for polish value measurements on curved laboratory specimens from accelerated polishing wheel tests. The values measured, BPN = British pendulum (tester) number for flat surfaces and polish values for accelerated polishing wheel specimens, represent the frictional properties obtained with the apparatus and the procedures stated herein and do not necessarily agree or correlate with other slipperiness measuring equipment*.
   8.2. This standard is published by the ASTM E17.23 committee on Surface Characteristics Related to Tire Pavement Slip Resistance. It provides a method for

using the British Pendulum to test surfaces in general; the scope of the standard does not discuss roadway materials. The standard was originally published in 1961.

8.3. The test method has somewhat less detail than BS 7976-2; slider preparation is ten slips on “#60 grade silicon carbide cloth”, which appears to be coarser than P400 sandpaper in BS 7976-2. The slider materials include two options, one is the “natural rubber” as approved by the “Road Research Laboratory” of the UK in a 1964 paper. The other is a “standard rib tire for pavement” defined in ASTM E501.

8.4. Discussion: while ASTM E303 is occasionally mentioned in the context of pedestrian slips, both BS 7976-2 and AS 4586 / 4663 are more detailed and more focused on pedestrians.

9. ASTM D7032:2017. Specification for Establishing Performance Ratings for Wood-Plastic Composite and Plastic Lumber Deck Boards, Stair Treads, Guards, and Handrails. West Conshohocken, PA; ASTM International.

9.1. Scope: *This specification covers procedures to establish a performance rating for wood-plastic composite and plastic lumber for use as exterior deck boards, stair treads, guards, and handrails. The purpose of this specification is to establish a basis for code recognition of these products or systems in exterior applications. The products addressed in this specification are considered combustible. The plastic component of wood-plastic composites and plastic lumber covered by this specification shall consist primarily of thermoplastics. Deck boards, stair treads, guards, and handrails covered by this specification are permitted to be of any code compliant shape and thickness (solid or non-solid). Wood-plastic composites and plastic lumber are produced in a broad range of fiber and/or resin formulations. It is recognized that the performance requirements in this specification are valid for any material or combination of materials used as deck boards, stair treads, guards, or handrails. Details of manufacturing processes are beyond the scope of this specification.*

9.2. This standard is for the general performance of composite deck boards (e.g., “Trex”), and it includes a section on wet and dry slip resistance. It states that friction testing per ASTM F1679 (withdrawn 2006) is the preferred option, though ASTM D2047 (for dry-only polish coated surfaces using the James Machine) is another option. There is no friction threshold specified in the standard. This standard is adopted by the current (2018) International Building Code.

9.3. Discussion: ASTM F1679 was the test method for the English XL articulated strut tribometer (Excel Tribometers). It was withdrawn due to it being a proprietary device and because of the lack of a precision statement (R&R statistics from an ILS); ASTM requires a precision statement, and a proprietary device cannot be named in an ASTM standard when “alternates exist”. A different articulated strut tribometer could be asserted to be an “alternate” even if significantly different in function, performance and measurement.

10. ASTM F2508:2016. Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces. West Conshohocken, PA; ASTM International, https://doi.org/10.1520/F2508-16

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10.1. Scope: *This practice is intended to establish the procedures for validation, calibration, and certification of walkway tribometers. This practice provides a walkway tribometer supplier with a procedure and suite of reference surfaces to validate his walkway tribometer by properly ranking and differentiating the surfaces. This practice provides the user of a walkway tribometer with a procedure and suite of reference surfaces to test calibration of his instrument. This practice provides a procedure through which an entity may certify a walkway tribometer model, signifying that the walkway tribometer model has a completed and documented validation and interlaboratory study. This practice describes the necessary materials, specifications, and the cleaning process for reference materials, as well as the requirements for the validation of a supplier's walkway tribometer and calibration of a user's walkway tribometer. This practice applies to walkway tribometers without reference to the nature of the scale of the readings produced by them. The scale used in the reports of validation and calibration must be the same, and are to be those of the instrument or defined for the instrument.*

10.2. This standard is for correlation of tribometer units to human slip research conducted at the University of Southern California. It references the 2010 research paper by Christopher Powers et al[5] regarding a study in which eighty human subjects were used to rank and statistically differentiate four different reference surfaces (wet) as to their friction. In that research, on the same reference surfaces, a dozen tribometers were tested to see if they could rank and differentiate the reference surfaces in the same order as the humans.

10.3. The standard provides for the purchase of "identical" copies of the USC reference surfaces, and has a procedure (relying on a supplier's set of these surfaces) for statistical testing (termed "Validation") to see if any particular tribometer can rank and differentiate the reference surfaces correctly.

10.4. The standard has a procedure (relying on a user's F2508 reference surfaces) for statistical testing (termed "Calibration") to see if the user's tribometer unit can rank and differentiate the reference surfaces to within a 95th percentile variation of the supplier's Validation results.

10.5. The standard also provides a procedure for conducting and documenting an ILS in accordance with ASTM E691; this section (termed "Certification") was added due to the lack of R&R data in most US tribometry methods (in 2013).

10.6. The standard states that it does not establish a "safe threshold" of friction for a walkway surface.

10.7. Though sometimes implied to be a test method (e.g., in ANSI/ASSE A1264.2:2012), ASTM F2508 is a Practice and as such doesn't (per ASTM) lead to a test result; the standard relies upon the test procedure established by the tribometer supplier (or another entity).

10.8. Discussion: the CPSC project has many similarities to ASTM F2508, in that both humans and tribometers test the same surfaces and attempt to rank them in the same order with statistical differentiation. The "Calibration" section of F2508 has

[5] Powers CM et al. Validation of Walkway Tribometers: Establishing a Reference Standard. J Forensic Sci, March 2010, Vol. 55, No. 2

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been minimally followed, as the section in effect penalizes those tribometer models that have high repeatability; it is easier to pass Calibration with an inconsistent tribometer than with a consistent tribometer. The 2016 version of ASTM F2508 is currently being significantly revised to rely on 2018-2020 research by Christopher Powers at USC.

11. CEN Technical Specification 16165:2016. Determination of slip resistance of pedestrian surfaces – Methods of evaluation. Brussels; European Committee for Standardization

    11.1. Scope: *This Technical Specification specifies test methods for the determination of the slip resistance of surfaces in the most commonly encountered situations in which pedestrians walk. This Technical Specification does not cover sports surfaces and road surfaces for vehicles (skid resistance).*

    11.2. This Technical Specification (not yet a standard in CEN parlance) is nominally the European equivalent to BS 7976, as it contains a Pendulum specification like BS 7976-1, a test method like BS 7976-2, and a calibration procedure like BS 7976-3. This "TS" also includes a method for using the generic tribometer design typically manifested as the GMG-200, the device discussed above under DIN 51131.

    11.3. As to the test method, this TS uses Slider 96 and Slider 57 polymers; Slider 57 is slightly different from Slider 55 used in BS and AS standards discussed previously, and it comes from a different manufacturer. The slider prep calls for twenty slips on both P400 sandpaper and PLF, and calls for discarding sliders once the wear chamfer is 3mm wide (for Slider 96), whereas the wear chamfer can be 4mm wide in the BS and AS standards before the slider is discarded.

    11.4. The method provides for verification using a float glass plate and PLF (like the BS and AS standards), as well as a verification tile referred to only as the "Portuguese" tile.

    11.5. Discussion: there has been ongoing dialogue about the requirements for Pendulum polymers; some users claim that the discard guidelines (one year from manufacture) from some manufacturers are not well founded, but serve to sell more polymer. Refinement of the technical arguments for this and similar criteria are also ongoing.

12. NFSI B101.1:2020 Test Method for Measuring Wet SCOF of Common Hard Surface Floor Materials

    12.1. Scope: *This test method specifies the procedures and devices used for both laboratory and field testing to measure the wet static coefficient of friction (SCOF) of common hard-surface floor materials.*

    12.2. NFSI was for several years an ANSI accredited standards developer but NFSI chose to abandon ANSI accreditation (and its requirements) in January of 2020.

    12.3. This NFSI document suggests that any of the five tribometers NFSI "Approved" for SCOF testing can be used to test to the same friction threshold, with an implied (but undocumented) measurement equivalence. These tribometers are all dragsleds:

        12.3.1. The TRACSCAN, a rebadged FSC 2011 (MCS Mechanik UG) sold by the NFSI President's family; this device is nearly identical to the BOT-3000.

        12.3.2. The TRACSCAN 2, which is not described on the TRACSCAN website.

12.3.3. The Universal Walkway Tester, the predecessor to the BOT-3000, which its manufacturer (Regan Scientific) does not service as it is considered obsolete.

12.3.4. The GS-1 (Impact General Inc.), a small computer-driven motorized dragsled with a single round slider.

12.3.5. The ASM 825A (American Slipmeter), a manual dragsled the user actuates with a lanyard. It has a triad of 13mm diameter polymer sliders.

12.4. This NFSI document recommends that the tribometer meet their ILS procedure, which is included in a nonmandatory Appendix that is not part of the "standard" – and as such has never been subject to consensus approval. To comprise its six different "independent labs", two operators each use the same three tribometers.

12.5. This NFSI document establishes friction thresholds but these do not have specific technical foundations. NFSI in the document a list of dozens of references they claim support their friction threshold and method, though some of these in fact are conflicting.

12.6. Discussion: Since abandoning ANSI accreditation, NFSI still refers to its documents as "standards", but they do not result from an open consensus approval process comparable to that undergone by any of the other methods described in this review. NFSI has eliminated from its "consensus approval" process any requirement for them to address specific negative comments with specific written responses. NFSI's has repeatedly refused (over 10+ years) to respond to technical inquiries regarding its "standards"; as such, other method options are superior.

13. NFSI B101.3:2020 Test Method for Measuring the Wet DCOF of Hard Surface Walkways

13.1. Scope: *This test method specifies the procedures and devices used for both laboratory and field testing to measure the wet dynamic coefficient of friction (DCOF) of common hard-surface floor materials.*

13.2. This document is the DCOF equivalent of NFSI B101.1, with all of the same issues as discussed for that document.

13.3. The NFSI "Approved" tribometers for DCOF testing include:

13.3.1. The GS-1, TRACSCAN, and TRACSCAN 2 described above.

13.3.2. The ASM 925 (American Slipmeter), a motorized dragsled that rests on the walkway and when actuated slides a single 13mm diameter polymer disc along under the device.

14. BS 8204 standards (London; BSI Standards Limited):

14.1. BS 8204-2:2003+A2:2011 Screeds, bases and in situ floorings - Concrete wearing surfaces. Code of practice.

14.1.1. Scope: *This part of BS 8204 gives recommendations for constituent materials, design, work on site, inspection and testing of in situ concrete direct finished base slabs, with concrete as the wearing surface, and wearing screeds (formerly known as high strength concrete toppings and granolithic toppings). It applies to both ground-supported floors and suspended floors.*

14.2. BS 8204-3:2004+A2:2011. Screeds, bases and in situ floorings - Polymer modified cementitious levelling screeds and wearing screeds. Code of practice.

14.2.1. Scope: *This part of BS 8204 gives recommendations for the design and installation of trowel finished polymer modified cementitious levelling screeds and wearing screeds, where the proportion of polymer solids based on the mass of dry cement is at least 4 %, as bonded screeds applied to direct finished concrete slabs, fine concrete screeds and to existing concrete floors within buildings. This British Standard does not apply to unbonded screeds, floating screeds, pumpable self-smoothing screeds, or those laid monolithically, neither does it apply to two-component aqueous thermosetting polymer dispersions.*

14.3. BS 8204-4:2004+A1:2011. Screeds, bases and in situ floorings - Cementitious terrazzo wearing surfaces. Code of practice.

14.3.1. Scope: *This part of BS 8204 gives recommendations for the materials, design, work on site, inspection and testing, and cleaning and maintenance for in situ cementitious terrazzo flooring. It is intended for terrazzo contractors, specifiers, builders, designers and main contractors. It gives recommendations for in situ terrazzo flooring applied as a wearing surface on a concrete base or screed*.

14.4. BS 8204-5:2004+A1:2011. Screeds, bases and in situ floorings - Mastic asphalt underlays and wearing surfaces. Code of practice.

14.4.1. Scope: *This part of BS 8204 makes recommendations for the types and grades of materials, design, work on site, protection, inspection and testing, maintenance and repair for in situ mastic asphalt for flooring applied as a wearing surface or underlay, incorporating waterproof membranes where required. It is applicable to mastic asphalt applied hot to concrete bases and screeds and concrete suspended floors. It is intended for mastic asphalt contractors, specifiers, builders and designers, and main contractors. It gives recommendations for mastic asphalt flooring in buildings applied, as an underlay or as a wearing surface, on a concrete base or screed.*

14.5. BS 8204-6:2008+A1:2010. Screeds, bases and in situ floorings - Synthetic resin floorings. Code of practice.

14.5.1. Scope: *This part of BS 8204 gives recommendations for the design and installation of in situ synthetic resin flooring, based on liquid synthetic resin binders in which curing takes place by chemical reaction of the resin components, used internally in buildings. The synthetic resin floorings are bonded to direct finished concrete slabs, polymer-modified cementitious or fine concrete screeds and to existing concrete floors. Annex A gives recommendations for the design and installation of resin terrazzo flooring. Synthetic resin floorings applied to other materials such as timber or metal are not covered by this code of practice. The installation of resilient sports surfacings based on synthetic resins is not covered by this code of practice*.

14.6. These standards reportedly[6] cite or permit the use of the SlipAlert tribometer (SlipAlert LLP). This apparatus utilizes a small wheeled cart that rolls down a fixed-length inclined ramp, and there is a frictional slider fitted to the underside of the cart. When the cart comes off the ramp at speed, the friction is electronically measured; it is an energy dissipation device (as is the Pendulum)

14.7. Discussion: The UK Health and Safety Executive (HSE) analyzed the SlipAlert in 2006[7], and while they believed it had some uses, it was stated that "it is recommended that when friction measurements are critical (e.g. for a forensic investigation, product specification, etc) the Pendulum test should be used." The SlipAlert would be unsuitable for this CPSC project as the inclined ramp is nearly a meter long; usage in an actual bathtub would not be feasible.

15. Guidelines Issue 5:2016, The Assessment of Floor Slip Resistance. UK Slip Resistance Group.

15.1. This document is a best-practices guide for British Pendulum use. It includes information on device setup, slider preparation, and maintenance. It specifies 3 different verification surface: PLF, float glass, and a "Pavigrés" reference tile. Of interest is that CEN T/S 16165 specifies (as mentioned above) a "Portuguese" reference tile, for which the accepted measurement range (34 +/- 5 PTV) is basically the same as UKSRG Issue 5 cites for the Pavigrés tile (32-36 PTV).

15.2. This document also provides guidance on testing profiled (3D) surfaces, stairs, and slopes, and advises on interpretation of results. It recommends a friction threshold of 36 PTV, though with many caveats.

15.3. This document advises that surface roughness measurements (Rz specifically) are useful for a more thorough characterization of walkway friction. It does state that Rz values do not capture the shape of roughness features; a particular Rz value may be shared by surfaces with significantly different pedestrian friction.

[6] http://www.slipalert.com/hse/
[7] https://www.hse.gov.uk/research/hsl_pdf/2006/hsl0665.pdf

TASK I-4B

TRIBOMETERS SUITABLE FOR MEASURING BATHING SURFACE FRICTION

CPSC PROJECT # 61320621Q0068

	TRIBOMETERS								
	BOT-3000E	**British Pendulum**	**GMG-200**	**English XL**	**Tracscan**	**GS-1**	**ASM 825**	**ASM 925**	**SlipAlert**
Portability	**1**	**1**	**2**	**2**	**1**	**2**	**2**	**2**	**1**
Notes:	Heavy	Bulky, heavy			Heavy				Bulky
3 proven verification surfaces	**0**	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**0**
Notes:	1 surface rated by manufacturer			1 surface rated by manufacturer	2 surfaces of undocumented provenance				No surfaces claimed by manufacturer
ILS data available	**2**	**2**	**2**	**2**	**0**	**0**	**0**	**0**	**0**
Notes:					ILS data considered confidential				no ILS data
Not a proprietary design	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
Notes:	Proprietary		Not proprietary but requires complex electronics	Proprietary	Proprietary	Proprietary	Proprietary	Proprietary	Proprietary
Test procedure or standard available	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Notes:	ANSI accredited standard	Multiple accredited standards	Test procedure in a "Technical Specification", not a standard	Manufacturer procedure, no active standard	"Standard" from unaccredited developer				Manufacturer procedure, no standard
Concave/profiled surfaces may work	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Notes:	Unsuited to 3D profiled surfaces as device wheels "drive" over features during measurement	Wide spring-loaded slider, constrained trajectory, soft slider polymer available	Unsuited to 3D profiled surfaces as device has unconstrained tethered travel with inconsistent trajectory	Unsuited for 3D profiled surfaces as slider can rotate/translate in use	Unsuited to 3D profiled surfaces as device wheels "drive" over features during measurement	Unsuited to 3D profiled surfaces as device has unconstrained tethered travel with inconsistent trajectory	Unsuited to 3D profiled surfaces as device has unconstrained tethered travel with inconsistent trajectory	Unsuited to 3D profiled surfaces as has a single 13mm diameter slider which may be smaller than the 3D feature	Unsuited to 3D profiled surfaces due to unconstrained cart travel
Totals:	**5**	**11**	**8**	**5**	**2**	**3**	**3**	**3**	**2**

0 = does not meet
1 = adequate
2 = excellent