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Forensic Considerations Regarding Traction and Tribometry of Bathing Surfaces

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Abstract

In 1974, the federal Consumer Product Safety Commission (CPSC) funded a study of injury patterns involving bathing surfaces. The study found the majority of injuries were due to slips and falls. The data from the CPSC-driven tribometry research was used to develop (with the cooperation of bathing surface manufacturers) a standardized test specification and minimum traction threshold. The standard that resulted in 1979, ASTM F462, was a positive step forward — but over 36 years the shortcomings of this long-obsolete standard have become increasingly evident. Nevertheless, F462 remains the sole codified standard for bathing surface traction in the United States. This paper will discuss the limitations of F462, the use (and misuse) of the standard in claims resolution and litigation, the efforts to modernize F462, and some considerations for investigating bathing surface incidents.

Keywords

Premises liability, bathing, bathtub, pedestrian, slip resistance, tribometer, traction, barefoot

Author's Note

Following completion of this paper, ASTM F462 was formally withdrawn by ASTM, though it continues to be used in the absence of a replacement.

Introduction

A forensic case involved a man who allegedly slipped and fell in a hotel bathtub in May of 2013. This plaintiff's expert conducted testing of the bathtub in accordance with ASTM F462, *Standard Consumer Safety Specification for Slip Resistant Bathing Surfaces,* and asserted that the bathtub did not meet the requirements of that standard[1]. The specifics of this case and the countering of that expert's assertions provided context for the following analysis of F462.

Efforts have been considered for years regarding the replacement of F462. Recent methodologies have provided new options for modernizing F462, but one of the complicating issues is that bathtub traction is federally regulated.

Summary of the Initial Timing of ASTM F462 and Related Standards

- ASTM F462-1979 was first released in May 1979. It has been reapproved without change repeatedly since then — most recently in 2007.
- The September 1979 revision of ANSI/ASME A112.19.1, *American National Standard for Enameled Cast Iron Plumbing Fixtures,* referenced F462[2]. This ASME standard, and its subsequent revisions, are referenced, in turn, by the U.S. government (e.g., 24 CFR 3280.604 for Manufactured Housing).
- The 1984 revision (released in July 1985) of ANSI/ASME A112.19.4, *American National Standard for Porcelain Enameled Formed Steel Plumbing Fixtures,* referenced F462[3]. This ASME standard is also referenced by the U.S. government.

Federal Foundations of ASTM F462

In late 1973, ASTM's newly founded F15.03 Subcommittee on Safety Standards for Bathtubs and Shower Structures began contacting plumbing product manufacturers at the direction of the also recently formed CPSC toward an effort to address bathing surface safety through standards[4]. Federal funding also went in 1974 to Abt Associates for a survey and analysis of National Electronic Injury Surveillance System (NEISS) bathroom incident data, which included slip incident data involving both textured and untextured bathing surfaces as well as incidents wherein the

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surface had soaps or oils on the surface[5]. This survey did not involve any evaluation of human traction *requirements*, nor traction measurement of incident-involved bathtubs. The findings of the Abt Associates report listed as stated goals that "every tub and shower stall will be provided with a standing surface which is slip resistant," and that "realistic test methods are badly needed." The means of facilitating this were to include an analysis of the "parameters of movement associated with accident sequences" and a focus on accurately simulating the wet bare foot and the bathtub conditions (e.g., soapy) present in bathtub slip events.

With CPSC support, the National Bureau of Standards worked with F15.03 committee to create what became the F462 standard. As a minimum traction threshold value (for bathing surfaces) was to be established, it was necessary to choose a tribometer, a test-foot material, and a liquid contaminant.

The three final candidates for the tribometer were the Horizontal Pull Slipmeter (HPS), the British Pendulum, and the then-new NBS-Brungraber Mark I tribometer[4]. The Mark I was chosen due to its combination of portability and ability to be calibrated across its measurement range. It had been designed by civil engineering professor Robert Brungraber, PhD, PE, in 1975, with funding from the National Bureau of Standards (NBS, now the National Institute of Standards and Technology or NIST) — hence the name "NBS-Brungraber Mark I." At one time, the manufacturing drawings were reportedly available through NBS, as it was a publicly funded design. The tribometer was one of the first readily portable tribometers (i.e., suitable for field use) on the market in the United States.

The selection of the liquid contaminant was a lengthy process[6]. Considerations included whether to use a soap or detergent, what concentration to use, and whether the prepared soap solution would be stable over time[7]. It was discussed whether to prescribe a single formulation, but the eventual choice was any soap compliant with federal specification P-S-624G or ASTM D799 (withdrawn in 2000).

The Abt Associates report had called for finding a testfoot material that would simulate the skin of the bare foot. But several explored options (including a shredded leather/rubber composite, the tanned skin of unborn calves, and neoprene foams) did not prove useful, due to their measurement performance or limitations in reliable sourcing[7]. Eventually, Dow Corning's silicone rubber Silastic 382 was chosen[4].

As mentioned, a goal within the Abt Associates report was to analyze the "parameters of movement associated with accident sequences," yet the eventually chosen traction threshold value was not based on actual human slip research. The value was chosen based on *comparative* traction measurements of 50 different bathing surfaces (i.e., bathtub A versus bathtub B, not bathtub A versus human traction requirements) provided by various manufacturers in 1976 — and tested with a single Mark I tribometer. The 50 tested surfaces included both porcelain-coated and plastic/composite products. The threshold – a static coefficient of friction (SCOF) value of 0.04 – was chosen simply to exclude those bathing surfaces on the market that had no slip-resistance traction/texture features at all[4].

Analysis of the Technical Foundations of F462

In ASTM F462, the traction level of the bathtub is to remain at or above 0.04 for the life of the manufacturer's guarantee. Since the 0.04 SCOF minimum traction threshold requirement in F462 has no correlation to actual reliably determined human traction research, from a forensic investigation standpoint, testing to F462 does not tangibly address the actual safety provided to humans by the available traction of a bathing surface.

Given that one of the key goals of the comparative bathing surface testing was to eliminate non-textured surfaces, it is ironic that the F462 requirements have not prevented some bathtub manufacturers from making reportedly compliant bathtubs that have no apparent slip-resistance texture features (see **Figure 1**).

Figure 1
A new commercial "F462 compliant" porcelain enamel bathing surface with no visible texture features.

Analysis of Competence of ASTM F462 — Tribometer

ASTM F462 specifies the use of only one tribometer. Dr. Brungraber's company (Slip-Test) manufactured the Mark I tribometer until about 1992; Dr. Brungraber retired in 2010, and neither parts nor service have been available for the Mark I since 2010*.

The Mark I's test measurement performance is susceptible to the device's internal friction; the design utilizes two sets of parallel stainless steel shafts upon which components slide (see **Figure 2**). As such, this design is sensitive to manufacturing dimensional tolerances and manufacturing consistency — yet the manufacturing drawings for the Mark I (which date from 1975) were created without a thorough tolerance analysis or the application of Geometric Dimensioning and Tolerancing (GD&T)[8]. The effect of unit-to-unit variability sources can be studied across a population of tribometer units, but there is no evidence this was done in the development of the Mark I. Further, to the authors' knowledge, there has never been a published reproducibility study conducted with the Mark I, though the need for one was highlighted back in 1977 in NBS 953[9].

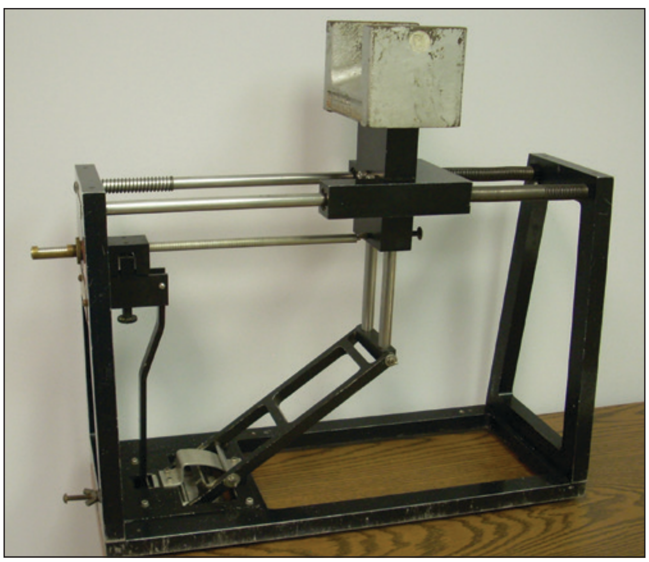

Figure 2
NBS-Brungraber Mark I tribometer.

Reproducibility/repeatability analysis, conducted using an *interlaboratory study* (ILS, aka "round robin" study) shows the statistical differences between measurements obtained by different operators using different units of the same test device on the same test samples[10]. Such testing should capture variability introduced by differences in as-manufactured tribometer part dimensions, internal friction, operator technique, and operator interpretations of the test method. Reproducibility/repeatability statistics provide critical information as to whether measurements made with a test device bear a reliable relationship to either: 1) a standardized threshold value (e.g., 0.04 SCOF); or 2) measurements made by others.

Reproducibility/repeatability data are frequently referred to as the *precision* of a methodology. ASTM's *Form and Style for ASTM Standards* guideline (also known as the "Blue Book") currently require that a precision statement be included in any ASTM standard test method within the first five years following initial publication, and test methods that do not achieve this are withdrawn[11]. At a minimum, the net effect is that a Mark I operator cannot know how his or her measurements relate to the measurements obtained in the 1976 comparative bathing surface study, or how his or her measurements relate to those of other operators. In a typical litigation setting, if an expert witness's analysis methodology cannot be duplicated by others, the expert witness may be subjected to a *Daubert* (or similar) challenge[12].

Neither F462 nor Slip-Test prescribed any particular maintenance or manufacturer calibration requirements for the Mark I tribometer, and no manufacturer has offered maintenance services for the Mark I in more than five years. As such, the comparative functional condition of all the 22- to 39-year-old Mark I tribometers in existence is uncertain. While F462 specifies the use of only the Mark I, there are forensic investigators who will use an alternative (non-Mark I) tribometer on a bathing surface and reference F462 — often without competent expert opposition. But such a methodology is technically indefensible (quoting from Powers et al):

> "The fact that the measurement of friction is a function of both the material being tested and the measuring system itself explains why several studies have shown that different devices yield different COF measurements for the same surface[13]."

Considering this in a forensic context, there is no reason to expect that measurements made on a bathing surface with a tribometer other than a Mark I would be comparable to those of a Mark I — and, as such, the measurements would be irrelevant to F462.

Another key issue with F462 testing is the SCOF value of 0.04 (specified as the minimum threshold). On

* See author John Leffler's disclosure following the conclusions section.

a level surface, the Mark I doesn't actually function at a measurement value of 0.00, so the operator must offset the starting position of the device to a measurement of about 0.01 - 0.02. This is the effective "zero" traction for the device. Therefore, the F462 "passing" measurement of 0.04 represents a value just barely beyond this effective "zero" point (i.e., the lower limit of the tribometer's measurement capability) on a measurement scale that goes to 1.00. In other words, the "passing" value is 2% higher than an unmeasurable value.

Over the years, some of these issues have been brought up in negative votes against ASTM's periodic re-approval ballots for F462. The standard is widely criticized and is a regular candidate for withdrawal, but it is the only standard for bathing surface traction. On this topic, *Haney v. Marriott International, Inc.* may be of interest to the reader[14]. The CPSC has requested that the standard remain in place until a replacement is published. The complexities and costs of creating a new "competent" F462 (which will be discussed later in this paper) are perhaps the primary reason why it remains unchanged.

Forensic Case Inspection of Subject Hotel Bathtub

An inspection revealed a porcelain enamel-coated metal bathtub shown in **Figure 3**. According to the hotel manager (who had been at the property since 1986), the bathtub was likely original to the building's 1975-76 construction. The brand, model, and manufacturer's warranty information for the bathtub were unknown; destructive removal of the bathtub would not necessarily have provided this information.

Figure 3
Incident-involved bathtub.

A pattern of the bathtub manufacturer's slip-resistance traction features was visible across the bottom surface of the bathtub (see **Figure 4**). If the subject bathtub were to be subject to the requirements of modern standard ASME A112.19.1M, the traction features would be required to come within certain distances of the sides of the bathtub — the subject bathtub conformed to these modern dimensional requirements.

Figure 4
Slip-resistant features along bottom of subject bathtub.

Analysis: Applicability of Standards to Subject Bathtub

Assuming the manager was correct that the subject bathtub dated from 1975 or 1976, ASTM F462 was still being developed. As such, there were no applicable slip resistance requirements. There were no requirements for bathing surface traction until September 15, 1979 when F462 compliance was first required by reference in ASME A112.19.1M-1979.

If the subject bathtub was manufactured after September 15, 1979, depending upon its construction, it may have been required by the ASME A112 standards to meet ASTM F462. ASTM F462 states in section 5.3 that "the slip resistance of the bathing surface shall remain at or above the level required by this specification during the life of the manufacturer's guarantee." It is highly unlikely that the subject bathtub, which was (based on the manager's testimony) at least 29 years old, was still under the manufacturer warranty in 2013. Further, the ASME A112 standards focus on new plumbing fixtures (e.g., bathtubs), and there was no discussion of warranties, guarantees, or durability of slip-resistance traction features.

Summary of Forensic Considerations in the Context of Subject Incident

- As a prefacing note, this paper discusses extrinsic factors of the subject forensic case. There were intrinsic considerations as well, as the plaintiff had potentially contributory medical conditions. However, intrinsic issues are not the focus of this paper.

- If the bathtub was original to the hotel construction, F462 was not yet adopted at that time, and there were no standard requirements in place for bathtub traction.

- If the bathtub was subject to ASTM F462 at the time of manufacture, that standard does not require any particular level of slip resistance beyond the period of the manufacturer warranty. It was reasonable to conclude that the decades-old subject bathtub was out of warranty, so F462 would not apply.

- The ASME A112 standards do not add any bathtub slip resistance durability requirements beyond what is specified in F462. It was reasonable to conclude that the subject bathtub was out of warranty, and thus would not violate those standards.

- The plaintiff's expert's results from his Mark I testing cannot be reliably correlated to the F462 traction threshold requirements — he did not use the Mark I utilized in the F462 research, and there is no reproducibility analysis describing the effects on measurement results of different operators using different Mark I tribometers on the same surface. Because of this, his methodology also was not reasonably reproducible by other parties — making it a candidate for a *Daubert* or other reliability challenge.

- Even if F462 was applicable to the subject bathtub, test results for the subject bathtub would not assist the triers of fact with reliable information regarding the safety of the bathtub floor surface due to the issues with the technical foundations of the standard.

- Given the described issues with ASTM F462, the adequacy of an in-use bathtub's traction typically gets down to the question of reasonable notice:
    - If a property holder has not (in the reasonable conducting of business) been made aware of a pattern of bathtub slips that cannot be linked to bathtub-traction-unrelated issues (e.g., claimant intoxication, persistent and atypical bathing lubricants, rough child play, or claimant intrinsic medical issues), then arguably they do not have reasonable notice of a bathtub hazard. In the context of another matter, see *Billings v. Starwood Realty et al* [15].
        - The subject hotel had four reported bathtub falls between January 2008 and May 2012. Of those four, two had contributing factors (one person was a toddler, and the other was reaching outside the bathtub for a towel). This arguably does not comprise a significant pattern, given the thousands of guests that stayed at this hotel every month.
    - Bathtub manufacturers do not publish recommendations (or, more importantly, methods) for property holders to periodically analyze the traction of their bathtubs. In the absence of such recommendations, the property holder does not have actionable reasonable notice provided by the manufacturer that the installed bathtubs may (over time) lose their slip-resistance characteristics to the point of becoming hazardous.
    - If a property holder does not have the opportunity to visually observe (through reasonable practices of inspection) that the slip-resistance traction features of a bathtub floor surface have obviously worn out, then arguably they do not have reasonable notice of a bathtub hazard. Complicating this further, not all "F462-compliant" bathtubs have observable slip-resistance traction features. Lastly, there is no objective method established in industry to reliably verify that a bathtub's traction features have indeed "worn out."
        - The subject bathtub had visible slip-resistance traction features across its bottom surface to within the perimeter edge requirements of modern ASME standards.
    - In the event that property holders decide they want to increase the traction of their bathtubs,

there are a variety of options (sandblasting, chemical etchants, "sticky" coatings, appliques, rubber mats), all of which are advertised as competent by their manufacturers. Yet the foregoing discussion points out that there is little relevant science behind the codified traction of *new* bathtubs, and the science behind the traction of aftermarket refurbishing treatments (for which there are no standards) may not be objective. An understanding of such details is likely beyond the expertise of the average property holder.

Future Opportunities for Bathing Surface Safety Standards

It is reasonable to conclude that public safety would be better served by a more competent traction standard for bathing surfaces (i.e., a standard with a reliance on human slip research). As mentioned, such a standard would be complex and costly to develop — which is perhaps why it has not happened to date. Nevertheless, recent methodologies may provide useful barefoot-testing-based foundations for a competent replacement of ASTM F462, subject to consensus approval. Elements to consider with this human slip testing may include:

- Intrinsic elements:
  - Selection of the desired gait parameters to be modeled (e.g., velocity, straight walking versus step-over, changing direction, stride length versus step-over height).
  - Definition of what comprises a "slip" (e.g., foot velocity, slip distance) in this context.
  - Management of slip expectation in test subjects.
  - Test subject population characteristics (e.g., age, sex, mass, height, disabilities, number of subjects).
  - Barefoot sole conditioning (e.g., dry versus wet skin).
  - Accommodating differences between test subjects' barefoot skin friction due to factors such as callouses and the depth and orientation of dermal ridges.
- Extrinsic elements:
  - Different bathing surfaces to be represented (e.g., porcelain enamel, mosaic tile, gelcoat/fiberglass, vacuum-formed).
  - Geometry of test surfaces (planar versus the slight concavity of a bathtub).
  - Differences in friction mechanisms (e.g., fine roughness of textured porcelain enamel versus molded dimples on vacuum-formed plastic surfaces).
  - Patterns and geometry of traction features (e.g., geometry and distribution of "medallions" of texture on otherwise untextured enamel; geometry and distribution of molded dimples on plastic surfaces).
  - Contaminant supply to the test surface (e.g., static or flowing liquid, use of soap or detergent, concentrations).
  - Whether to record forceplate data, slip events (slip/near-slip/no-slip), or both.
  - Agreement on an objective and standardized way to uniquely characterize, describe, and refer to the different surface materials and traction features.

Consistent with ASTM F2508 and DIN 51130, one key goal of any proposed human slip research should be to produce a suite of progressively slippery standardized reference surfaces that can be made available in duplicate [16, 17]. These surfaces can be used by bathing surface manufacturers for comparison to production surfaces and by tribometry researchers to verify whether a particular tribometer can rank and differentiate the suite of surfaces in the same order the humans did. With reference surfaces, rather than having a minimum traction *threshold value* based on one tribometer (like with ASTM F462), a future standard could be based on the tribometer-specific traction value measured on a minimum-traction *threshold surface* (i.e., a reference bathing surface that provides the traction needed to deter human slips in testing). With such a threshold surface, different tribometers (properly qualified) could be used for testing, regardless of what measurement scale they utilize or what value they measure on that threshold surface. Simply stated, this approach again allows for the establishment of a relative traction threshold value that is tribometer specific, and, in turn, would allow for the testing of bathing surfaces by tribometers that do not have ILS data. This is a critical concept in interpreting tribometer measurements and slip risk, as without the reproducibility/repeatability data from an ILS to rely on, an individual tribometer's traction measurements are not directly comparable to measurements from other units of the same model (i.e., Mark I to Mark I).

As it takes specialized production equipment to make bathing surfaces, existing bathing surface manufacturers would be the most obvious source for standardized reference surfaces. There would need to be agreement among them as to how to standardize both terminology and manufacturing processes for reference surface traction features — given expected concerns regarding trade secrets. Based on recent human slip research, it is possible that the minimum traction threshold will be raised above that of ASTM F462, potentially requiring different surfacing methods than are currently in common use [18]. Participation by the manufacturers would be advisable as well from the standpoint of gaining consensus approval for F462's replacement.

Recent Human Subject Research Relevant to Bathing Surface Traction

Bathing surface gait kinematics are markedly different than those of normal walking[20]. Shorter steps are taken, step-over thresholds are higher, and the bather is barefoot. The presence of wet or soapy surfaces (and past experience) may alert the bather to the need for caution [19,20]. Barefoot pedestrian testing is relatively rare in the literature. German standard DIN 51097 and research by Sariisik were both based on barefoot testing, though this testing was conducted on ramps [21,22]. Others have pointed out that the gait dynamics of walking on ramps are different than walking on a level surface [23]. As such, gait dynamics on ramps would be different from walking in or out of a (level) bathtub.

The friction mechanisms of bare feet (on wet surfaces) are significantly different from those of footwear. The components of footwear that influence underfoot traction include the outsole tread design, tread groove width, depth and orientation, outsole material and hardness, micro- and macroscopic outsole roughness, and heel contour. Characteristics of the human foot that affect the traction at the foot-floor interface include the dermal ridges of the skin on the heel (comparable to fingerprints), skin thickness, fatpad thickness and deformity, skin hardness, contour of the calcaneus, and skin conditions such as callouses. Moreover, these barefoot characteristics will vary between people, and potentially influence slip events during human subject testing and the development of a traction threshold.

Human slip research by Powers et al was useful in identifying a suite of progressively slippery reference surfaces for level walking (see ASTM F2508) — a concept (discussed above) that could aid in establishing reliable methodologies for improving bathing surface safety[13,16]. Another study that is perhaps more on point (as a conceptual foundation for F462 replacement research) is by Siegmund et al., in which test subjects stepped into and out of a bathtub that had been fitted with forceplates in the foot contact areas[18]. The forceplates were used to measure utilized COF during various combinations of bathtub entry and exit motions (and associated kinematics), with a flow of liquid contaminant within the bathtub.

Considerations for Tribometry of Bathing Surfaces

There has been much debate, from a tribometry standpoint, as to the appropriate test foot material (if any exists) to be used for the assessment of bathing surface traction. Medoff, Besser, and Marpet have reported on creating silicone rubber tribometer testfeet from human heel casts (to obtain realistic friction ridges), and they suggest that such testfeet would need a minimum of three layers to represent the skin, the underlying fat pad, and the calcaneous [24]. The challenges of creating a somewhat biofidelic "barefoot" tribometer testfoot are significant — most "skin tribometry" studies have not focused on bare feet.

Other work by Besser and Marpet has focused on dropping the guided bare foot of a seated human test subject onto a sloped test surface, and then repeating the test at progressively increasing surface slopes until the foot slips [25]. The tangent angle of the surface slope then corresponds to the slip resistance value of the surface.

Work by Blanchette and Brault in the preliminary stages (unpublished data) attempts to compare the COF of the ASTM F2508 adjunct reference surfaces as measured by several tribometer testfoot materials and cadaver heel pads.

Conclusions

- For the forensic case discussed, there was no evidence that ASTM F462 applied to the subject bathtub, nor that testing to F462 would have reliably informed the triers of fact.

- Given the issues with F462, some bathtub fall cases may instead rely on analysis of "reasonable notice" of a hazard — to the property holder and to the bather.

- Due to the issues with ASTM F462, both public safety and the field of forensic analysis are poorly served by the standard. It needs to be replaced as soon as practically possible.

- Replacing ASTM F462 would be expensive, time consuming, requiring of many disparate contributors, requiring of new human slip research, and requiring of government support.

Disclosures

In addition to employment as a forensic engineer, John Leffler is lead engineering consultant to tribometer manufacturer Slip-Test, Inc., a corporation formed in 2010 based upon the intellectual property and business inventory purchased from Dr. Robert Brungraber's original Slip-Test company, upon Dr. Brungraber's retirement. With that purchase, this author also received Dr. Brungraber's files, his former Mark I tribometer, and a small stock of Mark I parts, yet due to issues discussed in this paper, the tribometer was promptly sold in "as is" condition — there was no foreseeable use for it. Further, due to the Mark I's issues, no attempt has been made to offer servicing or parts for Mark I tribometers — as such work could not be warranted as reliable.

Mark Blanchette is the F13.40 Research Subcommittee Chair in the ASTM F13 Pedestrian/Walkway Safety & Footwear Technical Committee.

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