11 February 2024

John C Sotter
Vice President
Safety Direct America
26705 Loma Verde
Mission Viejo, CA 92691

Subject: Statement on Static Coefficient of Friction (SCOF) Testing and ASTM D2047

Dear John,

I appreciate your efforts in advocating for the withdrawal of ASTM D2047 and your commitment to ensuring that floor safety testing is based on scientifically valid methods.

I would like to state unequivocally that Australia has never had a standard relating to the static coefficient of friction (SCOF) because it is completely irrelevant in assessing the risk of slipping. There is no scientific association between static coefficient of friction and the probability of a slip occurring. The fundamental reason for this is that SCOF lacks biofidelity, it does not replicate real-world slip conditions, particularly on wet surfaces where water escapes around the shoe or foot, preventing the formation of a lubricating film that is necessary for an actual slip to occur. Consequently, static coefficient of friction does not provide meaningful or reliable data regarding slip resistance.

Furthermore, no tribometer used for measuring SCOF has ever been scientifically validated to demonstrate a correlation between its readings and the real-world risk of slipping. This remains a significant flaw, and for some reason, the test method still persists in the United States despite its clear shortcomings. There is no validation of SCOF testing in accordance with the requirements under ISO/IEC 17025 *General requirements for the competence of testing and calibration laboratories*, which mandates that any test method must have established validity. SCOF testing does not meet this requirement, and as such, it is not fit for purpose.

The findings in *Implications for the Development of Slip-Resistance Standards Arising from Rank Comparisons of Friction-Test Results Obtained Using Different Walkway-Safety Tribometers Under Various Conditions* confirm the inadequacy of SCOF testing. Specifically, ASTM C1028, which utilizes a manually pulled drag sled to measure static coefficient of friction, was found to be incapable of reliably distinguishing between the wet slip resistance of ceramic tiles. This is a clear example of why static coefficient of friction cannot be relied upon as a predictor of slip risk, as it poorly correlates with other methods that have demonstrated biofidelity, such as the pendulum test in accordance with AS 4586【32†source】. The continued use of SCOF-based testing methods lacks scientific substantiation and should therefore be rescinded.

Given these factors, static coefficient of friction testing should be rescinded entirely. If there is any justification for its continued use, it should be based on robust scientific evidence. The burden of proof must be on those advocating for its retention, not on those seeking its removal. I strongly encourage the ASTM Committee on Standards or any other relevant association to provide rigorous scientific validation if they wish to justify the continued existence of SCOF testing, particularly in relation to drag-sled meters, which are subject to the same inherent issues.

In Australia and New Zealand, we have long recognized that static coefficient of friction testing is misleading and useless in assessing pedestrian safety. It has been excluded from our slip resistance standards for decades, and I am not aware of any nation outside of the United States that continues to rely on SCOF testing for safety assessments.

If you require any further information or formal documentation to support your case, please let me know.

Best regards,

Carl Strautins (MAIOH, COH, CMatP, COHSPrac)
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Bachelor of Science in Materials Science
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MANAGING PROPERTY RISK

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Principal Occupational Hygienist & Materials Scientist
BSc (Materials Science)
Masters OHS Management
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Master of Science in Medicine (Clinical Epidemiology)

QUALIFICATIONS

- Master of Science in Medicine (Clinical Epidemiology), University of Sydney
- Masters of Science (Occupational Hygiene Practice), University of Wollongong
- Master of Occupational Health and Safety Management, University of Technology, Sydney
- Bachelor of Science in Materials Science, University of Technology, Sydney
- Diploma in Scientific Practice, University of Technology, Sydney
- Certificate IV in Assessment and Workplace Training, Strathfield Regional Community College
- WorkCover New South Wales Course in OHS Risk Management for Supervisors and Managers (2004)
- Advanced Building Regulation Course, University of Technology, Sydney

REGISTRATIONS AND PROFESSIONAL AFFILIATIONS

- Certified Occupational Hygienist (COH), Australian Institute of Occupational Hygienists (AIOH)
- Certified Materials Professional, Materials Australia (CMatP)
- Certified Generalist OHS Practitioner Member with the Australian Institute of Health & Safety (COHSPrac)
- Registered Building Consultant (Master Builders Association (MBA)
- Australian Tile Council – (former NSW secretary)
- Australian Stone Advisory Association
- Australian Ceramic Society
- Australian Standards Committee Member BD-094 Slip Resistance of Flooring Surfaces,
- Australian Standards Committee Member BD-044 Fixing of Ceramic, Natural and Reconstituted Stone Tiles
- Standards Australia committee CH-031 Workplace atmospheres, which oversees the Australian Standard for asbestos testing, AS 4964 Method for the qualitative identification of asbestos in bulk samples.
- Australian Standards Committee Member BD-070 Stairs,
- Australian Standards Committee Member SF-013 Platforms, Gangways, Stairways and ladders
- Invited member of the UK Slip Resistance Group
- ASTM International committee F13 - Pedestrian/Walkway Safety and Footwear
- Invited to participate in American National Standards Institute (ANSI) subcommittee B101.4 Test Method for Measuring the Wet Barefoot Condition of Flooring Materials or Products.
- Invited expert to participate in the European Standards Technical Subcommittee in the revision of the pendulum test method within CEN/TS 16165 Determination of Slip Resistance of Pedestrian Surfaces - Methods of Evaluation.
- NATA technical assessor for slip resistance testing and calibrations.
- National Association Testing Authorities (NATA) Accreditation Advisory Committee (inspections)
- National Association Testing Authorities (NATA) Accreditation Advisory Committee (Physical Performance Testing)
- SafeWork NSW Taskforce member for the Manufactured Stone Industry in response to the Legislative Council Standing Committee on Law and Justice inquiries for the '*First Review into the Dust Diseases Care scheme*' as part of the Hazardous chemicals and materials exposures baseline reduction strategy.

PROFESSIONAL PROFILE

Carl is a Certified Occupational Hygienist (COH) with the Australian Institute of Occupational Hygienists (AIOH), a Chartered Professional Member of the Safety Institute of Australia (CPMSIA), a Certified Materials Professional by Materials Australia (CMatP), a Registered Building Consultant by the Master Builders Association, and an Associate Member of the Human Factors & Ergonomics Society.

With a wealth of experience, he is sought after as an expert witness within District and, Supreme Courts for personal liability and health risk assessments arising from asbestos, dust and chemical exposures.

He holds a Bachelors Degree in Materials Science, a Masters Degree in Occupational Health and Safety Management, a Masters Degree in Science specialising in Occupational Hygiene Practice and a Master of Science in Medicine (Clinical Epidemiology). He also holds a Diploma in Scientific Practice, Certificate IV in Assessment and Workplace Training and successfully completed a short course in Advanced Building Regulation.

As an injury and health risk scientist and occupational hygienist, Carl combines medical, chemistry and engineering disciplines to anticipate, recognise, evaluate, control and communicate environmental stressors that may result in injury, illness, impairment, or affect the wellbeing of workers and members of the community. This includes the assessment of dusts, fibres, fumes, vapours, gases, noise, vibration and radiation within a range of industries.

In the area of slip resistance, testing and measurement, Carl has developed Safe Environments' procedures that are accredited by NATA to AS ISO 17025 *General requirements for the competence of testing and calibration laboratorie*s for slip resistance testing to the four methods within the Australian Standards and the calibration of pendulum and dry FFT devices.

Carl developed the accelerated wear slip test method and the structured quality management framework which is used in industry to assess sustainable slip resistance. He is am a member on Australian Standards Committees BD-094 *Slip Resistance of Flooring Surfaces* and SF-013 *Platforms, Gangways, Stairways and ladders*.

He has developed Safe Environments' procedures that are accredited by NATA to AS/NZS ISO/IEC 17020:2013 *Conformity assessment - Requirements for the operation of various types of bodies performing inspection* for hazardous materials inspections (including asbestos), asbestos soil sampling and asbestos clearance activities as well as AS ISO 17025 *General requirements for the competence of testing and calibration laboratorie*s for the *Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres asbestos air monitoring [NOHSC:3003(2005)]* and asbestos identification to AS 4964 *Method for the qualitative identification of asbestos in bulk samples*.

Carl has also been formerly assessed by NATA as an approved asbestos identifier and counter as well as a NATA Signatory for building materials and asbestos in soil.

In the field of lighting, Carl has assisted Safe Environments accreditation under AS ISO 17020 for luminous reflectance testing and luminance contrast testing in respect to access and mobility requirements to AS 1428 suite of standard. He is also involved in litigated matters where lighting factors play a role in personal injury.

As an industry expert, Carl is regularly sought to provide technical assistance in conducting third party audits of inspection bodies nationally for NATA. Carl has undertaken a number of roles in conducting asbestos and hazardous material inspections, air monitoring, site supervision of asbestos removals, clearance inspections, Health Risk Assessments (HRAs) and development of asbestos management plans nationally.

Carl was also involved in the review of the position paper released by the Australian Institute of Occupational Hygienists (AIOH), Asbestos and its potential for occupational health issues.

Carl has conducted asbestos and hazardous materials audits, soil assessments and management systems for a diverse range of government, industrial, commercial and retail properties

Previously employed by the CSIRO department of Building, Construction and Engineering, Carl has a strong understanding of building code requirements. Having undertaken short courses at UTS in advanced building regulation, he was part of the working group which provided the deemed-to-satisfy provisions in the National Construction Codes for slip resistance.

Carl has experience in testing and inspecting building products for compliance with Australian Standards as well as providing evidence in legal proceedings in expressing an opinion to being *'fit for purpose'* During his employment at CSIRO as a materials technologist and experimental scientist, he has assisted the building appraisals team for surfaces and finishes. This included reviewing relevant test methods and technically comparing test methods and assessing them to relevant aspects of the building code.

CAREER SUMMARY

2006-Present	Safe Environments, Principal Occupational Hygienist & Materials Scientist
2006-2008	Coffey Environments, OHS & Property Consultant Auditor
2003-2006	CSIRO – Materials Technologist
2002-2003	CSIRO - Technical Officer
2001-2002	CSIRO - Research Student

Safe Environments Pty Limited

Carl is a managing director of Safe Environments Pty Ltd a multi-specialist consultancy operating in the building, construction and property management industries. He provides the necessary guidance and risk minimisation strategies required by architects, construction companies and facility managers to ensure they mitigated their risk to property risk. He is engaged on a regular basis to provide expert opinion for disputes and legal proceedings.

Coffey Environments (formerly MPL)

Employed as A OHS and Property Consultant, Carl project managed Asbestos Surveys, Hazardous Materials Surveys and OHS Property Risk Audits for national clients such as Department of Defence, Australian Broadcasting Corporation, Stockland, Knight Frank, Macquarie Goodman and Valad Property Group.

CSIRO

Carl was first employed as a research student within CSIRO division of Building construction and Engineering conducting research on various tribometers in different conditions. He was commended by the Chief of Division for *"efforts and extreme diligence in collecting forensic data for litigious purposes in a number of particularly demanding physical conditions, whilst continuing to make valuable contributions to the team's R & D"*. Carls career quickly progressed as the leader of the slip resistance facilities in North Ryde within the CSIRO Division of Manufacturing and Infrastructure Technology as a Materials Technologist.

SEMINARS PRESENTED

- Designers Institute of New Zealand CPD Sustainable Slip Resistance Seminar at Auckland and Wellington Sponsored by Jacobsen Creative Surfaces, November 2008.
- Australian Tile Council Industry Seminar, October 2008 – Sustainable Slip Resistance.
- Master Builders Association (MBA) continuing professional development series, "Slip Resistance in Surface Areas and How to Ensure Compliance" August 2008.
- Full Frontal Tile and Stone Exhibition April 2008, Sustainable Slip Resistance – A Shift in Paradigms
- Qualicer '08, Xth World Congress on Ceramic Tile Quality, Castellon Spain "Sustainable Slip Resistance: An Opportunity for Innovation".
- In house seminars in 2008 for various architectural firms such as Alex Popov & Associates, Bates Smart, Cox Richardson Architects, DEM, E-2, Incorp, Krikis Taylor, PTW Architects, Quatro Design, Rice Daubney, Stockland, Tanners.

- International Ergonomics Society Conference on Slips, Trips & Falls 2007: From Research to Practice, Boston USA.
- Property Council of Australia, OHS Compliance, Operations and Facilities Management Course, 2006.
- Di Lorenzo Ceramics, What You Need to Know about Slip Resistance Seminar Series 2006 (formal CPD points for RAIA).
- New Era Enterprises, Asbestos Awareness Course 2006
- Insurance Surveyors Discussion Group, Slip Resistance Auditing 2006
- Property Council Of Australia, OHS, Risk & Compliance, Building Services Fundamentals Course, 2006
- Royal Australian Institute of Architects National Slip and Trips Seminar Tour (Sydney, Canberra, Darwin, Brisbane, Adelaide & Perth), as part of the RAIA Continuing Professional Development Program, 2005.
- Metz Breakfast Seminars, A Brief Introduction to Slip Resistance, 2005. Sydney & Brisbane.
- Tile Power Seminars, Slip Resistance, 2005
- The Australian Institute of Building Surveyors, Slip Trips and Falls Twilight Workshop, 2004.
- Institute Public Works Engineering Australia, Slip Resistance Management Systems, CivenEx 2004
- Institute of Strata Network Managers, Wesley Centre, 2003

PUBLICATIONS & CONFERENCES

- Qualicer '22 World Congress on Ceramic Tiling Featured Session *"Slip Resistance Flash Session"* presenting sustainable slip resistance and accelerated wear testing as part of the panel debate.
- Benjamin S. Elkin, Mark G. Blanchette, Grant Davidson, **Carl J. Strautins,** John Leffler, Gunter P. Siegmund (2021) 'Human slip-based tribometer standards: An update on progress in ASTM Committee F13' Extended Abstract from 21st Triennial Congress of the International Ergonomics Association, Vancouver, June 13 – 18, 2021.
- **Strautins, C**, (2020) 'Pendulum calibration, metrological traceability and reference material' Slips, trips & falls Conference Madrid 2020: "A vision for the future" February 13th-14th, 2020.
- **Strautins, C**, (2018) 'Measurement uncertainty and proficiency testing' Slip resistance symposium held in conjunction with Qualicer 2018 World Congress on Ceramic Tile Quality, Castellon Spain.
- **Strautins, C**, Daniel, M and Rowell, D (2017) 'Review of The Australian Inter-Laboratory Proficiency Testing Scheme' Slips, Trips and Falls International Conference 2017, Toronto 15-16 June 2017
- **Strautins, Carl** (2017) 'Development of Clinical Based Evidence in Assessing the Risk of Slip and Falls', Slips, Trips and Falls International Conference 2017, Toronto 15-16 June 2017
- **Strautins, Carl** (2017) 'Findings from Slip, Trip and Fall Public Liability Audits of Australian Shopping Centres' Slips, Trips and Falls International Conference 2017, Toronto 15-16 June 2017
- Bowman, R., Daniel M., **Strautins, C.** (2015) 'How valid are psychophysical assessments as an indicator of slip resistance?' Proceedings 19th Triennial Congress of the IEA, Melbourne 9-14 August 2015
- Bowman, R., Daniel M., **Strautins, C.** (2015) 'A comparison of psychophysical assessments and physical slip resistance measurements' Proceedings 19th Triennial Congress of the IEA, Melbourne 9-14 August 2015
- **Strautins, C.,** & Daniel, M., (2013) 'Integration of slip resistance values within a risk management framework: a human gait based approach using reference samples'. International Ergonomics Society International Conference on Fall Prevention and Protection 2013, Tokyo Japan
- **Strautins, Carl J** (2009), 'Sustainable Slip Resistance' Tile Today, Issue 62 March 2009.
- **Strautins, Carl J** (2008), 'What Your Mother Didn't Tell You About Slip Resistance' Tile Today, Issue 61 December 2008.
- **Strautins, Carl J** (2008) 'Sustainable Slip Resistance: An Opportunity for Innovation', Qualicer '08, Xth World Congress on Ceramic Tile Quality, Castellon Spain.
- **Strautins, Carl J** (2007) 'Enhanced Test Method for Assessing Sustainable Slip Resistance', International Ergonomics Society Conference on Slips, Trips & Falls 2007: From Research to Practice, Boston USA.
- Richard Bowman, **Carl Strautins** & My Dieu Do (2005) 'Beware of conflicting stone slip

resistance reports' Discovering Stone, March 2005

- Bowman R & **Strautins C J**, 2004, 'Wet slip resistance of ceramic tiles as a function of rubber test foot preparation' AUSTCERAM 2004, 29 Nov – 1 Dec 2004, Melbourne
- Bowman R, **Strautins C J**, Do, MD, Devenish D, and Quick G, 2004, 'Comparison of footwear for the oil wet ramp slip resistance test' Contemporary Ergonomics 2004, CRC Press, pp 33-37.
- Bowman R, Quick G W, **Strautins C J**, and McEwan T, 2003, 'Initial findings extracted from the CSIRO wet slip resistance database' Proceedings of International Ergonomics Association XVth Triennial Congress, 24-29 August 2003, Seoul, Korea, Vol. 6, 4 pp.
- **Carl Strautins** & Paul Bailey, (2004) 'Slips, Trips & Falls – Assessing Safety in Buildings', Building Product News
- Bowman R, **Strautins C J**, Devenish D and McEwan T, 2003, 'Practical Aspects of Slip Resistance of Ceramic Tiles' Tile Today, February, 20.
- Bowman R, **Strautins C J,** Westgate P, and Quick G W, 2002, 'Implications for the development of slip-resistance standards arising from rank comparisons of friction-test results obtained using different walkway-safety tribometers under various conditions' Metrology of Pedestrian Locomotion and Slip Resistance, STP 1424, M. Marpet and M.A. Sapienza, Eds., American Society for Testing and Materials, West Conshohocken, PA, pp 112-136.
- Bowman, R, Quick, GW, Devenish, DA and **Strautins, CJ** (2002) 'Practical aspects of slip resistance of stone' Discovering Stone, September, 2002.

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publication in ASTM STP 1424, Metrology of Pedestrian Locomotion and Slip Resistance

Richard Bowman,[1] Carl J. Strautins,[1] Peter Westgate,[1] and Geoff W. Quick[1]

Implications for the Development of Slip-Resistance Standards Arising from Rank Comparisons of Friction-Test Results Obtained Using Different Walkway-Safety Tribometers Under Various Conditions

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Reference: Bowman, R., Strautins, C.J., Westgate, P., and Quick, G.W "**Implications for the Development of Slip-Resistance Standards Arising from Rank Comparisons of Friction-Test Results Obtained Using Different Walkway-Safety Tribometers Under Various Conditions,**" *Metrology of Pedestrian Locomotion and Slip Resistance, STP 1424,* M. Marpet and M.A. Sapienza, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2002.

Abstract: This paper studies the extent to which different tribometers consistently rank the slip resistance of a series of different ceramic tiles, as measured by a number of techniques. An accelerated abrasion treatment was used to determine how the slip resistance might change with wear in service. It forms part of a wider study of the slip resistance of stone, concrete, vinyl, rubber and other pedestrian surfaces. Although most techniques ranked the tiles in a similar order, there were some notable exceptions. Underestimation or overestimation of available slip resistance may cause significant problems, whether in the evaluation of a new product or an existing walkway surface. It is important to determine when specific tribometers may give "incorrect" results on particular types of surfaces, in order that a more reliable assessment can be made. This may require the use of a different technique, a dissimilar test foot, or modified test procedures or parameters. When a hard rubber test foot was used, the slip resistance tended to reflect the altered surface roughness of the abraded tiles, but when a resilient rubber was used, there was a general increase in the slip resistance. These results confirm the complex interplay between surface topography and choice of test foot. The results also indicate that current commonly used test methods can yield results that poorly predict the traction available to a pedestrian, either when the product is new or after the surface wears. This study found that the manually-pulled 50-pound drag sled (as used in ASTM C-1028) was incapable of satisfactorily distinguishing between the wet slip resistance of ceramic tiles. The pendulum tribometer (used according to AS/NZS 4586, with TRRL rubber, similar to ASTM E-303) provided more reliable results than the English XL Variable Incidence Tribometer (used according to ASTM F-1679).

Keywords: slip resistance, tribometer, sustainable, ceramic tiles, coefficient of friction.

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with a maximum of 0.33. Buczek *et al.* [5] found that the mean required or utilised friction was 0.31 (± 0.07) for five able-bodied people, and 0.61 (± 0.26) for the affected side of five disabled people. Despite the small number of subjects, this study was used as the basis for the Americans with Disabilities Act requirements [6]. Although a much larger body of required-friction data has been generated in gait and biodynamics studies, it has rarely been explicitly published in the literature.

On the basis of the Building Research Station study [3], it was estimated that one person in a million would have a traction demand in excess of 0.4 for straight walking and turning corners. Pye [7] has since used the same raw data (for 87 men and 37 women, all fit and able and between the ages of 18 and 60) to publish Table 1. His risk analysis assumes that by statistical means the chance of a person exceeding a certain high coefficient of friction can be extended from a small population. Pye acknowledged that this was suspect. However, he opined that persons who walked in such a manner, so as to exceed regularly a coefficient of friction of 0.35, would often slip on wet floors, and learn to modify their gait so as to lower their traction demand.

Table 1 – *Relative risk associated with coefficients of friction between foot and floor (after Pye [7]).*

Risk	Walking straight	Turning: left foot	Turning: right foot
1 in 1 000 000	0.36	0.40	0.36
1 in 100 000	0.34	0.38	0.34
1 in 10 000	0.29	0.34	0.33
1 in 200	0.27	0.31	0.32
1 in 20	0.24	0.27	0.29

It should be anticipated that further larger studies will be conducted, where they also include a more representative population (including older people and persons with disabilities). If such studies indicate that the typical traction demand is 0.25 rather than 0.22 for the able bodied, the risk analysis will need to be recalculated. However, since one must not discriminate, it would be appropriate to conduct analyses for the whole population as well as its segments: the temporarily able bodied, those with functional limitations, and those with severe functional limitations.

The available traction is as much a function of the footwear and any contaminants present, as it is of the floor surface. In Europe, interlaboratory studies of the slip resistance of footwear were conducted where comparisons were made between test machines (based on force plates or load cells) and people walking (both on the level over force plates and on ramps) [8]. While the results were largely inconclusive because there was too little difference in the slip resistance of the footwear that was studied, the observed coefficients of friction depended on the technical test parameters of the test machines, e.g. vertical force, test speed, contact area and time of contact between the shoe and the floor. There were also some methodological problems relating to the use of test persons for assessing slip resistance. However, analysis of the German ramp-based test methods for determining the slip resistance of floors and shoes has shown that adequate test-subject training, standardization, and calibration improves the precision and limits the individual, test-person-dependent effects on the results [9]. English [10] has of test specimens against sets of reference materials (which represent a continuum of slip resistance from low to high traction). It is expected that the walkway surface, shoe bottom, or combination of both that is being evaluated will be ranked in comparison to the reference-set materials, bypassing the numeric values obtained by a specific test method or instrument. Part of the qualification process that instruments are likely to have to undergo is an evaluation that would demonstrate it to be appropriate for measuring the specific set of test conditions, for instance: the nature of the walkway surface, the test foot and lubricant or contaminant. It is anticipated that the new standard will include pass/fail thresholds for different activities such as walking, running, pushing a heavy load, descending a ramp, etc. This should essentially enable the establishment of classes of slip resistance that might be used in a similar way to the existing German classifications.

Unfortunately, contrary to what we might have learnt during high-school physics, polymers do not obey the classic laws of friction. It is thus important to have a better understanding of how the nature of polymeric soling materials might influence the test results. Pendulum-type tribometers operate based on the energy lost when a swinging spring-loaded test foot makes ground-contact over a specified travel distance. Andrew [14] used a modified form of the Pendulum, an Enhanced Laboratory Skid Tester (ELST), to study the energetics of transient contacts between polymers and inorganic substrates. When the ELST test foot swept over a surface, energy was dissipated by a number of mechanisms, some of which interact: reversible adhesion; disruptive adhesion; gross deformation; reversible micro-deformation; abrasive wear; mechanical alignment; and viscous drag. Perhaps the most important component in the energy loss was the wear of the test foot. Andrew also found that deposited films of test foot material on the test surface could strongly influence the observed coefficients of friction. Given the wide range and types of shoe soling materials, it is important to understand how the characteristics of the test foot can influence the measured coefficient of friction. This is fundamental to both the selection of appropriate test foot materials, and the interpretation (and extrapolation) of any test results that are obtained. Andrew [14] developed generalised energy loss equations for thermoplastics and elastomers, the two main types of polymeric soling materials.[2]

For a thermoplastic material, Andrew [14] could separate the frictional force into two separate components, a term due to adhesion and a term due to abrasive wear, by the use of experiments employing a combination of surface textures and lubricants. In lubricated sliding, the dominant frictional force for a thermoplastic appears to be abrasive wear. When dry, a rough test surface produces lower coefficients of friction than a similar smooth surface (since the rougher surface profile reduces the intimate area of contact

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[2] *Thermoplastics* are often simply called plastics. They are capable of being repeatedly softened by heat and hardened by cooling. Polyvinylchloride (PVC), high-density polyethylene (HDPE) and nylons are typical of the thermoplastic family. *Elastomers* have a low density, crosslinked molecular structure. These rubber-like polymers can be stretched at room temperature under low stress to at least twice their length and recover their original length upon removal of the applied stress. When heated, elastomers degrade rather than melt. Natural rubber, nitrile rubber (acrylonitrile butadiene) and ethylene-vinyl-acetate copolymers (EVA) are typical elastomers.

was 0.05, when six independent laboratories used their own VIT to test three types of ceramic tile under both wet and dry conditions.

Powers *et al.* [18] found that, when the VIT was used to test a dry smooth vinyl composition tile, it overestimated the peak coefficient of friction by 30%, when compared to healthy adults walking across the same surface on the same force plate at comparable impact angles. They believed that the differences in the measured utilised coefficients of friction were most likely related to the fact that the VIT test feet do not have the same vertical and horizontal accelerations of the pedestrian's lower leg at heel strike.

Our paper considers wet tests only, as we consider that dry tests on new walkway surfaces under uncontaminated situations is an artificial situation that rarely occurs in the real world. Most slips on dry surfaces involve some form of residual contamination, dust or other dry contaminant. In the absence of any contaminant, some very smooth, flat, high gloss surfaces will yield very high results that imply that they will be safer than walkway surfaces that have been proven to be safe, e.g. brushed concrete. We contend that it is better to concentrate on using a standardised contaminant (e.g. water, oil, glycerol, or as is appropriate to the study) that can be consistently applied, to predict how potentially dangerous a surface may be under dry conditions if it becomes contaminated. Notwithstanding this, it can be very useful to obtain a measure of the difference between the available traction under ideal dry and wet conditions, as the likelihood of a slip will tend to increase as the magnitude of the difference increases. While such testing might be most effectively performed in field studies, laboratory trials might yield useful results, particularly if the condition of the walkway surface is appropriately modified to simulate anticipated wear or maintenance conditions.

Experimental Method

Materials

A range of Australian and imported tiles were used in this study. They had a nominal size of at least 300 x 300 mm. Six of the tiles (tiles A to F) were from the same batch of tiles that had been used in an interlaboratory pendulum study, where 26 laboratories took part. While it is difficult to precisely describe the surface characteristics of tiles, Table 2 attempts to do so. Typical R_z (once known as R_{tm}) surface roughness figures are given.

Tile H was treated with a proprietary floor surface etching treatment product, thereby creating tile J. This resulted in a slight loss of gloss. In a related investigation, four further levels of etching treatments were also made on tile H in order to determine the extent to which the changes, that were visibly evident, could be detected by the tribometers (these tiles are not shown in Table 2).

Some tiles were also tested after being subjected to various numbers of abrasion cycles, using ISO 10545.7 Methods of sampling and testing ceramic tiles: Determination of resistance to surface abrasion - glazed tiles. The size of the abraded area (80 mm diameter) restricts this slip resistance testing to the SATRA STM 603 and the VIT.

The SATRA STM 603 is a laboratory-based tribometer that is a commercial derivative of the equipment described by Perkins and Wilson [19]. It allows accurate control of four key parameters: applied vertical force, speed of moving of the test flooring surface, static contact time[7] and exact point at which the coefficient of friction is determined.[8] The machine is PC-controlled to ensure accuracy and repeatability, and has its own on-board computer and monitor screen. Pre-loaded software controls the data acquisition and logs the data during every test run. Each of the reported results is the mean of at least four tests, where a 25 mm wide section of the test rubber was mounted on a metal block and tested at a 5 degree angle to the tile surface. 400 grit abrasive paper was used to prepare the test feet. The speed used was 100 mm/s. There was a static delay of 0.2 s, and the dynamic coefficient of friction was determined 0.3 s after sliding commenced. The 0.2 s static delay time is an inherent element of the SATRA TM144 test procedure.

Giles *et al.* [20, 21] have described the development and performance of the Pendulum, as well as factors affecting the results, standardisation of instruments and their long-term accuracy. The Pendulum is used in a number of standards, for example, ASTM Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester (E 303-93),[9] as well as AS/NZS 4586:1999 Slip Resistance Classification of New Pedestrian Surface Materials. The results, obtained in BPN units, were then converted to coefficients of friction.

The ASTM Standard Test Method for Determining the Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method (C 1028-96) uses a 76 × 76 mm Neolite®-Test-Liner test foot and a 50-pound drag sled. Manually pulled drag sleds are widely considered unacceptable.[10]

Experimental Results

The experimental results are given in Tables 4 and 5, and Figures 1 to 10, where the results in Figures 2, 3 and 4 have been placed in the order of the TRRL pendulum results. Unless otherwise stated, as in Figures 9 and 10, the VIT results are those where 400 grit paper was used for test foot preparation. For ease of comparison, the ramp results, usually quoted as angles, have been converted to coefficients of friction by using the tangents of the angles.

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[7] The static contact time is the delay in time between the test foot coming into initial contact with the walkway specimen, and horizontal movement of the flooring relative to the test foot.

[8] The dynamic coefficient of friction is automatically calculated in terms of the average, peak and snapshot values. The snapshot value can be programmed to occur at a specific point or distance after sliding commences, by specifying a time, given the speed selected for that test.

[9] The precision and bias statement indicates that a sample size of 5 is needed in order to ensure that the testing error stays within 1.0 BPN unit at a 95% confidence limit.

[10] Manually operated horizontal pull testers permit the test foot to substantially reside on the surface before applying the test force. As such, they are not suitable for making wet slip resistance measurements of footwear or walkway surfaces. Furthermore, manually operated horizontal pull testers are technically inappropriate due to uncontrolled, non-uniform and non-normal application of force and rate of force application.

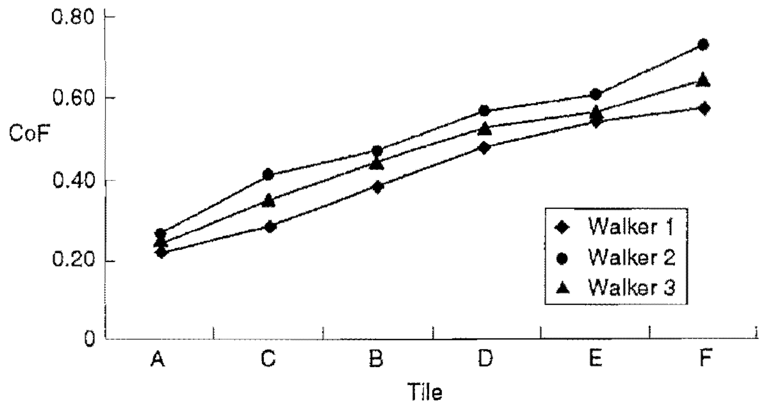

Figure 1 – *Influence of walkers on the RAPRA CH0001 test, where smooth Four S shoes are worn water runs over the specimens.*

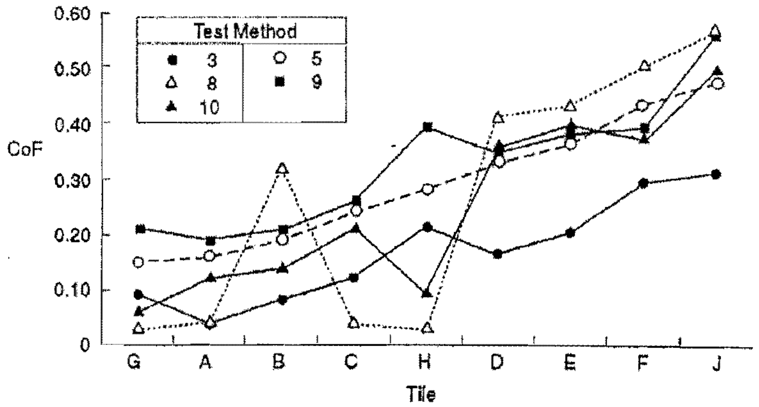

Figure 3 – *Comparison of TRRL rubber test results [SATRA (3); Pendulum (5; and VIT (8)] with wet barefoot (9) and oil-wet ramp(10) test results.*

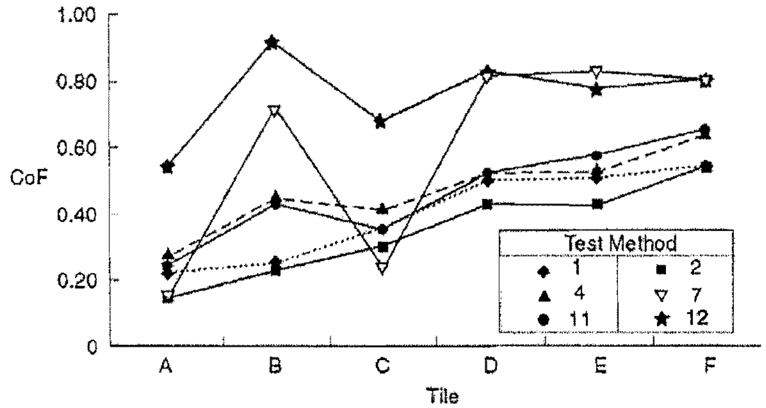

Figure 2 – *Summary of tests involving Four S rubber [SATRA, 400 N (1); SATRA, 100 N (2); Pendulum (4); shod-wet ramp (11)] and Neolite® Test Liner [VIT (7); and C-1028 drag sled (12)].*

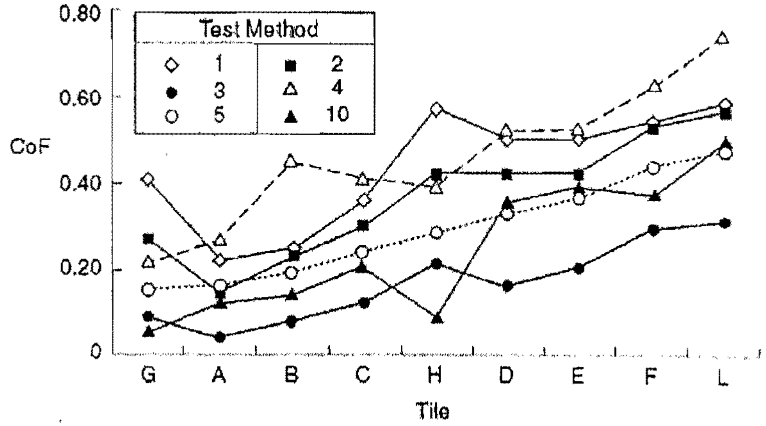

Figure 4 – *Comparison of SATRA [Four S, 400 N (1); Four S, 100 N (2); and TRRL (3)] and Pendulum tests [Four S (4) and TRRL (5)] with oil-wet ramp (10) tests.*

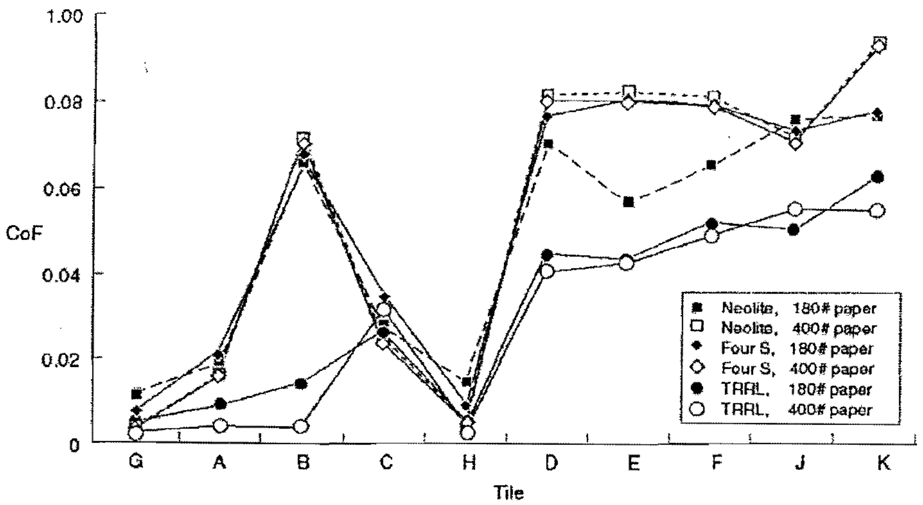

Figure 9 – *Summary of VIT results according to test foot and method of preparation.*

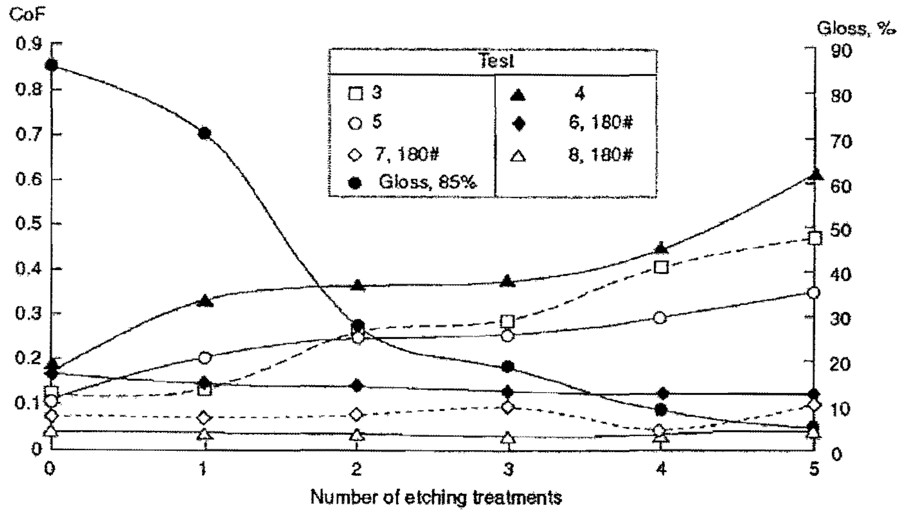

Figure 10 – *Effect of etching treatments on the slip resistance [SATRA, TRRL (3); Pendulum, Four S (4), TRRL (5); and VIT, Neolite® Test Liner (6), Four S (7) and TRRL (8)] and gloss of polished tile.*

The results have been plotted graphically to enable a direct comparison of the results, where it is possible to obtain a visual sense of how the ranking of the results differs, and where individual results or groups of results deviate from a trend established by the other results. The graphical representation also allows a comparison of differences in the relative magnitude of the results. The use of figures has been preferred to presenting the data as a series of correlations between the test methods due to the limited size of the data sets presented here. When larger sets of data are compared, the correlations can change. This may particularly be the case when resilient materials such as vinyls, rubbers and cork-based products are included in the comparisons.

though the results were so close as to be almost interchangeable (within the presumed limits of reproducibility for each test), the correlation coefficient was 0.88.

The wet barefoot ramp test is the only practical test method for determining wet barefoot slip resistance. The ramp test results are considered [11] to provide a reliable indication of slip resistance under the type of condition being tested (wet barefoot, oil-wet with profiles sole texture, water-wet with smooth soles).[11] Where a tribometer is being used to test a similar set of conditions, the ramp tests provide a sound basis for comparison. However, where the test results are dissimilar, it may still be possible to develop correlations for walking on horizontal surfaces. For example, the wet barefoot ramp and the wet TRRL Pendulum tests had a correlation coefficient of 0.94.

The wet barefoot ramp coefficients of friction are slightly greater than the wet TRRL Pendulum test results, with the largest difference being measured on the etched porcelain tile (Tile H, Figure 3). The harder Four S rubber gave significantly higher results than the wet barefoot ramp test (correlation coefficient of 0.92). Given the soft yielding nature of the sole of the human foot after prolonged water immersion, resilient test feet are likely to provide a better surrogate for the assessment of wet barefoot slip resistance.

The oil wet ramp coefficient of friction results were slightly less than the wet TRRL Pendulum test results (0.95 correlation coefficient). The Four S Pendulum correlation was 0.87, which may reflect that the nitrile rubber sole of the treaded boots has a IRHD hardness of 72. The largest difference between the oil wet ramp and the pendulum results was again measured on the etched porcelain tile This reflects the difference in viscosity between oil and water, and also the smooth macrotexture of this tile.

Choice of Test Foot Material

The hard Neolite® Test Liner and Four S test feet, when prepared with 400 grit paper, gave almost identical VIT results. For the three test methods where the TRRL and Four S test feet were compared (SATRA STM 603, Pendulum, VIT), the resilient TRRL rubber gave lower results than the harder, but less abrasion resistant Four S rubber.

One might expect that the TRRL rubber would lose more energy due to gross and reversible micro deformation than the Four S rubber, but would lose less energy due to abrasive wear. The selection of test foot material obviously has an influence on the magnitude of the coefficient of friction, but when the tiles are ranked in order of slip resistance for a given test method, the position of the products changes only slightly. However, such deviations may provide indications of the interacting energy dissipation mechanisms that occur when specific products are being tested. The ensuing insights should help to establish a basis for determining whether a certain test protocol is appropriate for assessing the slip resistance of a particular product in specific anticipated environmental exposure conditions.

The roughness of the test feet influences the measured coefficients of friction. The inherent roughness of some walkway surfaces will modify the roughness of test feet during the course of testing. The transient nature of the initial results that are obtained, as the test foot is being conditioned by the walkway surface, needs to be recognised.

[11] The development of the HSL SOP-12 test at the British Health and Safety Executive supports this contention.

that water can be squeezed out between surfaces where there is even a small residence time, this finding might appear surprising. However, unlike the ASTM C-1028 test where the full area of the 76 x 76 mm test foot is in contact with the tile surface, only the 25 mm wide trailing edge of the angled test test foot is in contact, simulating a condition where a slipping foot is still at an angle to the walkway surface.

English XL VIT Test Results

When compared to the other test methods, the VIT tends to underestimate the wet slip resistance of smooth polished, glazed or surface protected tiles, while overestimating the slip resistance of tiles with a textured or profiled surface. Use of the resilient TRRL rubber in the VIT gave better correlation than the hard Neolite® Test Liner and Four S rubber for tiles with a textured or profiled surface.

When the coarser 180 grit paper was used, the Neolite® Test Liner results were less extreme, in that there was a slight increase in the slip resistance of the smooth surfaces, and a decrease in the slip resistance of the tiles with a textured or profiled surface. The largest decreases were observed with tiles D, E, F and K. These results are inconsistent with the general finding [22] that the coefficient of friction rises with increasing roughness of the soling material.

Unlike the other water-wet test methods, the VIT did not detect an improvement in slip resistance due to acid etching. This is contrary to the findings of Di Pilla [23], who used a VIT to study the comparative effectiveness of ten floor surface treatment products on a glazed ceramic tile and a marble tile. Although the slip resistance of Di Pilla's untreated ceramic tiles varied significantly (from approximately 0.1 to 0.3), he detected a significant increase in slip resistance (to 0.4 and above) with six of the proprietary treatments. Given the limited reproducibility of the VIT [16, 17], the authors thought that the degree of etching might have to exceed a threshold before the VIT could detect a significant improvement. However, even when several etching treatments eliminated the gloss on the polished porcelain tile used in this study, the VIT was unable to detect an increase in slip resistance, see Figure 10. Porcelain tiles are typically more chemically resistant than ceramic tile glazes, and are much more chemically resistant than marble.

The VIT's overestimation of the slip resistance of tile B, when compared with the ramp and SATRA STM 603 tests, is of greater concern. This tile has a high gloss glaze coat and contains coarse grit particles that protrude above the background. The high VIT results suggest that the test foot interacts with the grit, but the vertical pressure is insufficient, particularly at low angles, for the test foot to interact with the high gloss glaze. The lower ramp test results and real world experience (the tiles were withdrawn from the market) suggest that the high gloss glaze determines the initially available pedestrian traction, rather than the coarse protruding grit particles.

The VIT results for the Neolite® Test Liner and Four S rubber test feet are very similar when they are prepared with 400 grit paper. When these rubbers were used in the VIT, they overestimated the slip resistance of tile D with respect to tile J, contrary to all the other test methods. However, when the 180 grit paper was used, this anomaly was corrected with the Neolite® Test Liner, but not the Four S rubber. These results confirm earlier findings [24] that the VIT results can depend on how the test foot is prepared. No specific control was exercised on the applied vertical force when preparing test feet in

Effect of Acid Etching

The SATRA STM 603, Pendulum and wet barefoot ramp tests were all able to determine an improvement in the slip resistance of the etched polished porcelain tile. The VIT and oil-wet ramp tests were unable to detect an improvement. Since oil is far more viscous than water, it was not expected that the oil-wet ramp would be able to detect the effect of acid etching.

Effect of Glaze or Surface Stain Protection

Tile D was similar to tile J, other than tile D had a protective surface coating (similar to a glaze but much thinner). The presence of the surface coating on this profiled surface resulted in a lower coefficient of friction with all test methods except the VIT when the hard Four S and Neolite® Test Liner rubbers were prepared with 400 grit paper.

Tiles A and G had the same porcelain body. Tile A was surface protected, while tile G had a limited amount of internal porosity exposed by the surface polishing treatment that the tile had been subjected to. The SATRA STM 603 and Pendulum tests yielded contradictory results for both rubbers (Figure 4).

Effect of Abrasion

The effects of abrasion have to be considered in terms of how the microtexture of each tile changes, as well as how the surface energy states may change, as measured by contact angles. Although the contact angle measurements that were made on some of the tiles confirm a change in the surface energy, this aspect is not considered further in this paper. One thousand five hundred abrasion cycles was generally sufficient to induce enough wear, whereafter there was generally little change in the slip resistance. However, in practice, one needs to look at the specimens to determine the extent to which the glaze or surface protection has been removed, or the body of an unglazed tile has been exposed. One also needs to consider how homogeneous or heterogeneous the surface of the product is, and the uniformity of the wear. Multiple use of the abraded tiles for making several slip resistance measurements has an associated risk of not always having a pristine surface available for testing.

With Four S rubber in the SATRA STM 603, abrasion resulted in improved slip resistance in tiles A and B that had high gloss (smooth) surface (stain) protection and glaze respectively (Figure 5). These changes were accompanied by a slight but consistent increase in R_Z surface roughness. The initial loss of slip resistance in tile C, and a subsequent slight recovery, was reflected in an initial loss of surface roughness, followed by a slight recovery. The initial improvement in the slip resistance of tile D was reflected in an increase in surface roughness. In tile E, the initial loss of slip resistance was also associated with a loss of surface roughness. In tile F, there was a very slight increase in slip resistance, which correlated with an initial increase in surface roughness. There was ultimately an overall loss of surface roughness, but with a further slight increase in the slip resistance. This was possibly due to increased porosity at the tile surface, as the "skin" of this extruded unglazed tile was removed.

standardised materials. Some surfaces may cause some tribometers to overestimate the available traction, leading to potentially dangerous situations. It is recommended that if such a ranking system is introduced, tribometers should undergo a rigorous qualification process with respect to the types of surfaces that they are fit for testing.

The manually operated horizontal pull tester (C-1028) was unable to satisfactorily distinguish between the wet slip resistance of the tiles. Since this test method significantly overestimated the wet slip resistance of tiles that offer little available traction, it should be withdrawn, in line with previous theoretical recommendations [1,2,28].

The process of making a slip measurement may modify the surface of the test foot and the tile surface [29]. In the case of the Four S rubber, which has poor abrasion resistance, coarse surfaces roughen the test foot, while smooth surfaces tend to polish it. This process is less pronounced in the highly resilient TRRL rubber, but in both cases, a thin film of rubber may be deposited on the tile, thus modifying the tile surface. It is well-known that when a Four S test foot is used in the Pendulum tester, the indicated slip resistance of a smooth product will continue to decrease as the test foot is slowly polished. This has led to the sensible UK Slip Resistance Group recommendation [25] that the Four S test foot be prepared on a 3 μm pink lapping film, whenever a product has a surface roughness less than 15 μm R_Z. The English XL VIT results are also considered sensitive to the method of test foot preparation in terms of the sanding protocol [24].

These experimental results raise important issues with respect to the meaning of slip-resistance measurements. One such issue, for example, is the relative accuracy of walkway-safety tribometer tests. If the available slip resistance of a new product is overestimated, it may be used in situations where there is an insufficient factor of safety. Dangerous situations will persist if slip audits overestimate the available traction. If the available slip resistance of a new product is underestimated, it may not be used in situations where it is eminently suitable for use. If a tribometer underestimates the available traction of an existing walkway surface, unnecessary remedial work might be undertaken.

Tiles A to F were used in an interlaboratory Pendulum study where 750 tiles were assessed by 25 other laboratories. While it was presumed that each set of tiles was identical, the tiles were not individually tested before being sent to all the laboratories. Although differences in the slip resistance of individual tiles might account for some of the large variation that was observed, one must ask the questions "How much reliance should be placed on individual results?" and "How do these results relate to real world traction demands?" The least variation was typically seen in laboratories with Registered Testing Authority status for the Pendulum test. This confirms the value of laboratory accreditation schemes and the need for certification of operators[12]. Controlling variations within a production batch is also of concern, as is accurately representing the predictable minimum slip resistance [30].

The extent to which the slip resistance of a product is sustainable over its anticipated life cycle is another important issue. If the available friction decreases significantly, some

[12] Richard Bowman, the principal author of this paper, is a Certified XL Tribometrist, and a NATA (National Association of Testing Authorities, Australia) assessor of laboratories accredited to conduct the Pendulum test.

To sum up, architects want certainty when specifying, and prefer simple systems. Risk management considerations require a prediction of future available traction. The European Construction Products Directive adopts a sensible approach in that products must be safe (slip resistant) at the end of their service life. Manufacturers should ideally test products both when new and after an appropriate accelerated wear test, before reporting the lower figure and the specific test specimen preparation protocol.

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