CAN WE DEVELOP SLIP RESISTANCE METRICS THAT ENSURE APPROPRIATE TILE SELECTION?

Richard Bowman

Intertile Research, Australia

1. ABSTRACT

This paper reviews several aspects of the state of the art of slip resistance testing in the context of trying to identify an ISO testing procedure that would provide suitable metrics for optimising appropriate tile selection. While existing test methods might be represented as being fit for purpose, there are several areas of test protocols that could and should be significantly improved. The use of test methods needs to be restricted to surfaces where reliable results will be produced. Appropriate limit and action values need to be agreed to assist specifications based on accelerated wear conditioning, whereby extended life cycle performance can be economically obtained. While the existing paradigm of solely assessing the ex-factory slip resistance of tiles is flawed and contrary to sensible regulatory measures, new data is required to establish credible evidence-based practicable standards.

2. HISTORICAL BACKGROUND

Injurious accidental falls are a major public health concern where falls prevention initiatives might be summarised as trying to delay the physical susceptibility of the elderly and mandating minimum slip resistance levels for the built environment. The public health community looks to the regulatory community to control construction and to ensure minimum evidence based standards. The European Construction Products Regulation[1] sensibly requires that flooring products must provide adequate slip resistance at the end of an economically reasonable working life. This indicates a need to assess the probable long term slip resistance characteristics. When it is known that tiles can exhibit different slip resistance behaviours and that some slip resistant tiles lose their slip resistance more rapidly, architects need an indication of long-term performance to differentiate between tiles that have the same ex-factory result or classification. The Goldilocks principle [1] recognises that in order for slip resistance to be 'just right' throughout a product lifecycle, there are also upper limits on the initial slip resistance.

The process of wear and the characteristics of the worn tile surface will ultimately determine if a product provides adequate life cycle performance. Since many ex-factory results of slip resistant tiles are known to be short-lived and thus illusory, little faith can be placed in many contemporary test results, except that tiles with relatively smooth surfaces and moderate to low slip resistance may only lose slight slip resistance. While the publication of more detailed information will assist specifiers, testing is expensive and manufacturers need to constrain costs.

The 1997 European mandate M/119 for floorings[2] called for a single and unique test method that could be applicable to all sorts of flooring product surfaces. The aim of CEN/TC 339, *Slip resistance of pedestrian surfaces - Methods of evaluation*, was thus to identify the appropriate criteria applicable to all the flooring surfaces and use this information to develop the unique test method. However, the mandate required justification of the situation where more than one method was referenced.

As Rowland [2] stated 'Much time and effort has been expended on comparisons between machines and arguments for and against dynamic and static measurement, without success. Yet regardless of this well documented confusion there is a desire by those who do not have in depth knowledge of the problem, to have one instrument which will give one reading which will cover all situations for all floors, all shoes/heels, all seasons, all contaminants, all ages, all infirmities, in fact for everybody, anywhere, anytime. It is perhaps now time to forget the much sought after and now obviously mythical 'universal test machine' that will, with one result tell us all we need to know, and concentrate on a composite solution which might in itself be quite complex'.

Several tribometers (slip resistance test devices) have been developed to provide a measure of the traction that is available from floors. Fervent support for various devices has perhaps been largely based on the investment made rather than on credible scientific evidence and an awarenessof the strengths and any limitations of the measuring technique. Several significant aspects of the reliability of results require consideration.

[1]http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:088:0005:0043:EN:PDF

[2]https://law.resource.org/pub/eu/mandates/m119.pdf

Slips are likely to occur when pedestrian gait demands more traction than is available from the floor. Pedestrian traction demand is only determined on force plates in laboratory situations. The relative ability of tribometers to accurately determine the available traction of floors is poorly known, particularly in the range where slips are most likely to occur. Such assessments of tribometers would seem to have been rarely undertaken, probably due to procedural uncertainties and the amount of work required.

Chang et al [3] have provided a partial example of a validation in a study where the utilised coefficient of friction (UCOF) was determined when subjects walked on five floor types. The Brungraber Mark II portable inclinable articulated strut slip tester (PIAST) was used to determine the available coefficient of friction (ACOF) where wet results of 0.002 and 0.032 were obtained for marble and a glazed porcelain. No slips were detected although the UCOF, 0.139 for marble and 0.127 for the porcelain, was much greater than the ACOF. It has been suggested that the PIAST has an excessive squeeze film effect that leads to underestimation of ACOF values. If so, one should consider what PIAST results (if any) would identify a slippery surface, as the 0.002 ACOF for the marble is very low. Yet might the study reflect a defensive gait and a slippery marble with a misleadingly low ACOF?

2.1. IS PACE MORE CRITICAL THAN ASSUMED?

Fischer et al [4] have identified two different types of walking (A and B), which differ in terms of the direction of heel movement at the critical time of heel strike. In walking type A, the foot comes in a steep path down to the floor and the final heel movement is backwards, such that a slip forward is highly unlikely. In walking type B, the foot descends in a flat path of movement towards the floor such that the final heel movement is forwards, such that a slip will depend on the difference between the traction demand and that available. Although the sample size was small, it seems that the majority of people are of walking type A at slow speeds, but convert to walking type B at higher speeds. If people are unlikely to slip when walking in type A mode, regardless of their traction demand, this will influence any calculation of the relative risk of a slip occurring.

In Chang's study [3], the mean walking speed for the dry floor surfaces (and those perceived as safe when wet) was typically between 1.9 and 2.0 m/s but decreased to a mean of 1.67 m/s for the water wet marble and porcelain, and to a mean of 1.31 m/s when glycerol wet. This might indicate that the walkers had switched from walking type B to type A. If so, the absence of slips might be due to the subjects perceiving the floor to be dangerous and adopting a safer gait, such that the study would not have determined the relevance of the PIAST results (although this was not the purpose of the study). Thus in order to determine how the output of a test method relates to potentially hazardous type B pedestrian demands, one might need to mask the hazard or use a bionic foot.

2.2. IS RISK OVERESTIMATED?

There has long been a tendency to determine how dangerous a floor surface might be, by referring to published studies of the ACOF associated with different slip probabilities for walking. Ideally one should first determine whether the test method used is likely to have underestimated or overestimated the ACOF. Harper, Warlow and Clarke [5] used force plate data for dry walks to determine that there was a one in a million risk of slipping with an ACOF of 0.36. Pye and Harrison [6] used the same data to calculate there was a 1 in 20 risk of slipping with an ACOF of 0.24.

Chang et al recently conducted another study [7] using a smaller sample, but one that provides more data about slip probabilities based on age, gender, footwear type and walking speed. At a fast walking speed, they determined a 1 in 20 risk of slipping with a mean ACOF of 0.272 and a one in a million risk with a mean ACOF of 0.326. One might expect that the first reaction to the news of such a narrow range of results between safe and dangerous would be that any tribometer would need to be exceptionally accurate in this critical range (or an adjusted range relevant to the tribometer output). However, when one examines the study in detail, the 95% confidence intervals are extremely broad and overlap. For a one in twenty risk, the 95% confidence intervals range between ACOF of 0.220 and 0.325 and for a one in a million risk, they range between 0.256 and 0.396. This confirms the variability of pedestrian traction demand, where the required COF data can show a difference in distribution between both feet for the same participant under each walking condition.

If someone was to obtain a coefficient of friction result of 0.29 from a tribometer, which was known to yield results that were consistent with the force plate calculated UCOF, the surface might be considered to represent a risk of 1 in 200 for fast walking, 1 in 10,000 for a female, and 1 in 100,000 for normal walking or someone over the age of 55. However, experts must explain the basis for any level of risk they declare.

Safety professionals obviously need to determine an acceptable risk level for different populations and activities. However, when undertaking such considerations, we know that we may have some control over workers' footwear and that we should recognise that the slip resistance of both the footwear and the flooring is likely to change.

The UK Slip Resistance Group has long considered that an ACOF of 0.24 or less (effectively < 25 BPN) indicated a high slip potential, and an ACOF of 0.36 or more (> 35 BPN) a low slip potential. A 3 µm pink lapping film was introduced to prepare pendulum sliders in BS 7976 in 2002. It was felt that this would address any issue associated with the progressive loss of slip resistance when the rubber test foot was slowly polished on smooth floor surfaces.

The same pink lapping film preparation has been adopted in CEN/TS 16165, AS 4586: 2013 and AS 4663: 2013. Lapping film preparation certainly yields lower results on highly smooth surfaces and thus allows better differentiation at the slippery end of the slip resistance spectrum [8]. However, if the results for a tile are changed from 36 BPN to 24 BPN, simply due to the method of slider preparation, does this mean that the risk of slipping has changed from one in a million to one in twenty, and that the tile now has a high rather than a low slip potential? Since the tile is the same, the real risk is unchanged. The method of determining the risk needs to be changed. Such overestimation of the level of risk may assist those who seek to maximise the ACOF and to protect the public, but it makes a mockery of the risk model, when there may be millions of wet uses of a high slip potential product without a single incident. The use of lapping film gives a lower bound to the slip resistance of a wet floor assuming a highly polished heel material, such that it may underestimate the ACOF of most pedestrians.

In Germany the ACOF must not fall below the limit value, which has been set at 0.30. Floors with ACOF greater than the 0.45 action value are considered safe, while intermediate results are considered to be conditionally safe: the situation is acceptable but additional protective measurements must be made. Perhaps there will one day be international agreement on such limit and action values, recognising that the current measures of ACOF are dependent on test foot material preparation.

In CEN/TS 16165, the GMG 200 uses an SBR rubber that has a density of 1.23 g/cm^2 and a Shore D hardness of 50. It is prepared with P400 abrasive paper. ANSI 137.1 specifies an SBR rubber that has a density of 1.23 g/cm^2 and a Shore A hardness of 95. It is prepared with P400 abrasive paper. Since there is little difference between a Shore A hardness of 95 and a Shore D hardness of 50, the GMG 200 and the BOT 3000 could almost be using the same rubber. Perhaps such an SBR rubber should also be adopted for the pendulum? It is harder than Slider 55 that has a Shore A hardness of 60.

It would seem sensible to determine if the P400 abrasive paper preparation causes an overestimation of the BOT 3000 and GMG 200 wet slip resistance. If so, a finer method of rubber preparation should be specified, but a product coarser than the 3 micron pink lapping film (that might generally underestimate wet pendulum slip resistance). However, such decisions can only be made on the basis of extensive evaluation, and correlation of the results with the observed performance of products. The most relevant evidence might be obtained by determining the ACOF of floors where accidents have occurred, particularly when they are measured in conditions similar to those at the time of the incident.

2.3. FURTHER REFLECTION ON THE PRESENTAND PAST

After much deliberation CEN/TC 339 published a technical specification CEN/TS 16165 in 2012. It applies to all floor surfaces and contains the two German ramp tests (oil wet and wet barefoot), two variants of the British pendulum test (slider 96 and slider 57 test rubbers prepared with pink lapping film) and a proprietary German tribometer (GMG 200).

ISO/TC 189, Ceramic tiles, WG 10, Slip resistance, is now seeking to produce a slip resistance test method for ceramic tiles, where tile manufacturers globally would strongly prefer a single test method. However, this will be frustrated by the required use of specified test methods in some countries. While German needs were satisfied (CEN/TS 16165 incorporated DIN 51130, DIN 51097 and DIN51131), Italians must use the Tortus to satisfy their national disability access legislation. Italian regulators must determine if there is valid data to support retention of the Tortus or adoption of another method.

While similar frustrations are likely to occur in other countries, ISO/TC 189 is expected to seriously consider adopting the BOT 3000 tribometer, which is specified in ANSI A137.1- 2012, the American National Standard Specifications for Ceramic Tile, and has also been incorporated as a requirement in "Section 2103.6, Ceramic Tile" of the 2012 International Building Code[3] that is used in many countries.

ANSI A137.1 requires a minimum wet DCOF AcuTest value of 0.42 for ceramic tiles for level interior spaces expected to be walked upon when wet. According to the standard, which does not address areas other than interior level spaces, tiles with a wet value of less than 0.42 are only suitable for floor areas that will be kept dry. It states that COF shall not be the only factor in determining the appropriateness of a tile for a particular application. The specifier must determine tiles appropriate for specific project conditions, considering by way of example, but not limitation, type of use, traffic, expected contaminants, expected maintenance, expected wear and manufacturers' guidelines and recommendations.

2.4. AN IMAGINATIVE EUROPEAN PARTIAL SOLUTION

Given the several confounding issues that complicate the measurement and use of slip resistance data, it is worthwhile considering the imaginative approach that was taken by the European SlipSTD Consortium[4]. A key objective of the Consortium was to overcome vested National interests and reach consensus on a new harmonised and unbiased means of evaluating floors and slip resistance based purely on objective information relating to the intended use of the floor. Engels [9] discussed this work during Qualicer 2012 with a specific focus on surface topography and sustainable slip resistance.

It is significant that the SlipSTD Consortium [10] found that slip resistance could be correlated with 3-dimensional surface topography where two parameters, Pk, the core roughness, and Pp, the height of the profile above the mean line, were used to characterise tile surfaces. Group 1 comprised smooth non-profiled tiles with Pk < 50 µm and Pp < 90 µm could be tested with the pendulum but not the ramp. Dynamic coefficient of friction measurements with tribometers such as the FSC 2000 (the forerunner of the BOT 3000) and the GMG 200 were considered to overestimate the actual slip resistance on the smoothest tiles due to slip-stick effects. Group 2 comprised gritty tiles with discernible microroughness with Pk > 50 µm and Pp > 90 µm. Any of the aforementioned test methods was considered suitable for determining the slip resistance of Group 2 tiles.

Group 3 was broken into three (lower, mid and upper) levels where the lower-level tiles (with Pk > 100 µm and Pp > 200 µm) had a macrorough, structured surface; the mid-level tiles (with Pk > 150 µm and Pp > 300 µm) a more pronounced surface structure; and the upper-level tiles (with Pk > 300 µm and Pp > 700 µm) a profiled surface, shape factors and a displacement volume. The FSC 2000 and GMG 200 tribometers were considered unsuitable for measuring the Group 3 tiles, where the slip resistance might be underestimated due to a loss of surface contact. The pendulum was considered unsuitable for measuring the slip resistance of the upper-level Group 3 tiles as the results were impaired by impact variation on the profiled surface. The ramp was considered the only method suitable for measuring the slip resistance of such tiles.

[3] http://publicecodes.cyberregs.com/icod/ibc/2012/index.htm

[4] SlipSTD Consortium. http://www.fgk-keramik.de/de/0_rumpf/down/Slipstd.pdf

However, how reliably do the specified ramp tests predictwet ACOF when casual footwear is worn?

Wetzel [11] conducted extensive studies involving over 100 types of safety and casual footwear and almost 100 flooring materials using multiple slip resistance parameters and methods. His results reveal that the oil wet ramp test does not predict the real world performance of footwear on water wet floor surfaces, and neither does the ISO 13287 slip resistance test for footwear. Some unclassified surfaces with low oil wet angle results (< 6°) could be walked on wet safely by 90% of the footwear, whereas one R10 ceramic tile (18.8° result) could only be walked on safely when wet by less than 20% of the footwear. Although Wetzel has suggested reference materials and parameters that might enable better prediction of real world slip resistance performance, he has also suggested obligatory slip resistance values for casual footwear as his research has suggested that such footwear has a 30% influence on the occurrence of falls on water wet floors.

When a diverse range of pedestrian surfaces is tested using several methods, there is likely to be some agreement between test methods for some products but also some seemingly anomalous divergent results [12]. For example, such results might be used to indicate that the English XL VIT overestimates the slip resistance of high gloss glazed tiles that have coarse particles penetrating above the surface. As such, is that tribometer suitable for assessing some or all Group 2 and Group 3 lower-level tiles?

Since the ramp test method is not portable, the pendulum can be used where on site measurements must be made on highly profiled surfaces (upper-level Group 3 tiles). However, the measurement protocol should be precisely defined (as in AS 4586 and AS 4663) in order to maintain the sanctity of the pendulum operational principles.

The SlipSTD Consortium further categorised hard floor coverings (tiles) into three classes according to the expected type of contamination and state of maintenance [10]. Class 1 comprised tiles for internal pedestrian areas that are foreseeably clean and dry and are routinely maintained as such. Class 2A comprised tiles for internal pedestrian areas for eseeably contaminated with water and/or dry contaminants; and Class 2B comprised tiles for internal pedestrian areas for eseeably contaminated with high viscosity contaminant ssuch as oil and grease.

While the SlipSTD sub-levels and classes are somewhat confusing and potential users would benefit from a revised classification system, Class 1 requirements are essentially satisfied by Group 1 products, where the tiles can be readily maintained (in accordance with the SlipSTD PAS recommendations). Group 2 or Group 3 lower-level products are required for Class 2A scenarios, whereas Group 3 mid- or upper-level products are required for Class 2B scenarios.

One advantage of the Consortium's use of optical topography measurements is that surfaces (or replicas of surfaces) can be compared after varying times of usage, enabling insights to be obtained as to how the surface texture changes with use and how the slip resistance is affected. It was anticipated that fundamental such knowledge concerning the influence of surface characteristics on the slip resistance would enable the development of ceramic tiles with improved performance.

2.5. SUSTAINABLE SLIP RESISTANCE

Strautins [13] used a washability machine to develop an accelerated conditioning procedure for tiles. This device, which wears an area of suitable size for wet pendulum (or BOT 3000) testing has also been used by Engels [14, 15] for assessing the cleanability of porcelain tiles.

Muñoz*et al* [16] and Engels [9] have confirmed Strautins' basic approach using shorter accelerated conditioning procedures. Muñoz*et al*used a scouring pad on a commercial polishing line, where short accelerated wear treatments provided a reasonable indication of the slip resistance of ceramic tiles in both internal and external long term trials involving over 100,000 pedestrian uses. Engels [9] used a 15 cycle treatment with a coarse abrasive stripping pad, where the slip resistance after the induced wear corresponded to that of a canteen entrance after 18 months actual wear. While the pad Engels used is marketed as being unsuitable for use with ceramic tiles (for obvious reasons of induced slip resistance loss), it is sobering to reflect that the practice of over specifying slip resistance often leads to the installation of tiles that cannot be as readily cleaned as had been anticipated, whereupon the cleaning contractor may resort to the use of inappropriate maintenance practices such as the use of overly abrasive pads.

Such accelerated treatments basically use nylon pads impregnated with abrasives, where the variables include the type and amount of abrasive, the applied pressure, the operating speed and whether the operation is undertaken wet or dry. Although the final texture imposed on porcelain tile surfaces by the industrial polishing process is slightly asymmetric [17], regions in the tile centres have more consistent texture than the outer tile edges. There is likely to be a greater problem of inconsistent wear if hand held polishing equipment is used to abrade 1.0 x 0.5 m boards of mounted tiles.

Although Engels [9] and Muñoz *et al* [16] have provided an indication of the relationship between their accelerated procedures and in situ wear, any relationship will be a function of the characteristics of the tile, the amount and type of liquid and solid soiling materials, the amount and nature of the pedestrian traffic, and the maintenance program. Strautins' procedure involves less pressure and thus more cycles, but also has greater potential for discrimination. Issues to be considered include whether there is an optimum number of cycles, and if there is a slip resistance level at which the conditioning should be terminated.

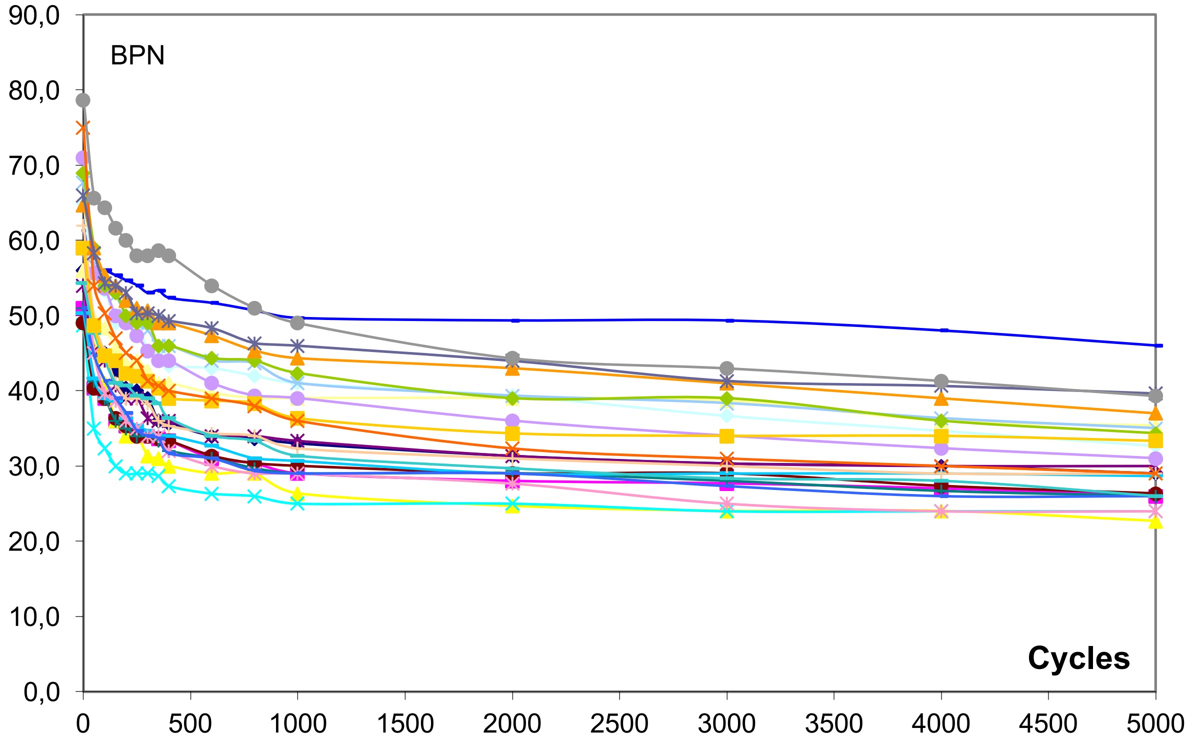

Figure 1 *Slip resistance loss for 24'slip resistant' ceramic tiles using Strautins' accelerated wear conditioning, measured using slider 96 prepared with P400 abrasive paper.*

Figure 1 reveals the typical loss of slip resistance for ceramic tiles using Strautins' accelerated conditioning procedure [13] with a green 3M Scotch Brite pad in a washability device operating at 50 cycles/min. The results typically show an initial rapid loss of slip resistance, particularly over the first 50 cycles. Twenty of these tiles lost 10 BPN or more in the first 100 cycles, and 23 of them lost a further 5 BPN in the following 300 cycles. The 500 cycle stage has been widely used as an indication of possible long term slip resistance, even though further loss occurs under the accelerated conditioning regime. Although one should expect less slip resistant products to suffer less loss of slip resistance, Strautins' data was based on P400 abrasive preparation of the slider 96 rubber. Where a product with an ex-factory value of 43 BPN might lose 20 BPN with 500 cycles, the loss might only be about 5 BPN where a white abrasive-free pad is used for the same number of cycles.

It is well accepted that the use of corundum abrasive media can cause abrasive wear in tiles that does not occur in real world usage [18]. Thus extent to which abrasive pads should be used to accelerate the wear of tiles needs to be considered in the context of their likely usage. The use of abrasive free nylon pads should be considered for accelerated wear in bare foot situations where there is no scratching dirt. Furthermore, there may be a synergistic effect between abrasive media in the presence of alkaline or acidic solutions, some accelerated conditioning research studies should explore the simultaneous use of dilute cleaning chemicals.

2.6. PENDULUM SWINGS

While the pendulum is well suited in several respects for determining the slip resistance of ex-factory and artificially worn tile samples, there is still a need to ensure that the instrument is used consistently and, more importantly, that the results are not inappropriately biased by variations in the test feet. CEN/TS 16165 specifies two types of rubber, sliders 96 and 57, where the numbers relate to the permitted IRHD hardness, for example 96 ± 2 in the case of slider 96. Slider 96 was formerly known as Four S rubber (standard simulated shoe sole) a proprietary material developed by the Rubber and Plastics Research Association (now Smithers Rapra Technology) solely for slip testing use. While the formulation and processing are intellectually protected, other companies have produced rubbers as potential competitive materials. BS 7976, AS 4586, AS 4663 and many other national standards use slider 55 rather than slider 57, which was recently developed as a compromise between the TRL rubber slider 55 and CEN slider 59.

There are at least two suppliers of slider 57. The IRHD hardness is permitted to vary from 55 to 61, and the Shore A hardness from 57 to 63. The manufacturer also has to issue a certificate of conformity for the Lübke resilience, a batch characteristic. Unfortunately, quite different slip test results can be obtained using compliant sliders from different manufacturers, and there can also be batch to batch variation. Bowman [19] previously asked "If the coefficient of friction is related to the hysteresis loss properties of a rubber, its Young's modulus, its abrasion resistance and other characteristics that can be quantified by existing test methods, why are these not being applied to better define and improve the consistency of existing or potential new slider materials?" The SlipAlert slider was formulated for slip testing purposes with characteristics that would give similar results to Four S rubber, but with greater consistency and endurance[5]. Given the poor abrasion resistance of the Slider 96 test feet, perhaps the SlipAlert rubber slider should be adopted for the pendulum, after comprehensive specification of its critical characteristics.

While tile manufacturers may seek to minimise the number of slip resistance test methods to restrain costs, slip and fall experts need to be able to determine the relative contribution of a tile to injurious incidents. While they might use different footwear materials to assist in such a task, it would seem sensible for tribometer manufacturers to standardise upon a type of test foot material and a consistent method of preparation. If experts are able to choose whether to use the BOT 3000, the GMG 200 or the pendulum, the confusion might be lessened by standardising on a primary rubber test foot.

[5] Bailey, M., (2015). Personal communication. SlipAlert, UK

2.7. ANTICIPATING FUTURE SLIP RESISTANCE ISSUES

Since Australian slip resistance design has been based on the oil wet ramp, the wet barefoot ramp, and the pendulum tests since 1999, and Europe has only recently adopted CEN/TS 16165, it seems appropriate to share some insights. While the oil wet ramp R classifications may be excellent for specifying industrial workplace floors (particularly when augmented by volumetric displacement requirements), it is now considered that the R classifications are less useful in public areas where there is no control over the type of footwear worn. As the SlipSTD Consortium study [10] indicates, there is a need to consider the suitability of any given test method for the anticipated usage conditions.

The wet pendulum test is considered most appropriate for public conditions where any footwear can be worn, except that wet barefoot ramp results should be used to select tiles for wet barefoot areas. Use of a resilient rubber slider in the pendulum seems [20] most appropriate for assessing the in situ slip resistance of wet barefoot conditions. Such a slider is also likely to be more relevant when investigating incidents where soft soled shoes were worn. However, even where specifications are based on ramp test results, wet pendulum tests should still be conducted for risk management purposes: all parties need unambiguous benchmark data prior to installation; and only portable tests can be used once the tiles are installed. Pendulum tests on accelerated conditioned samples can also help to determine which products might give the best life cycle performance.

The results of most slip resistance tests are highly dependent on which materials are used to act as a surrogate for footwear. While hard (slider 96) rubber and more resilient (slider 55/57/59) rubbers have been used, and there are concerns about the consistency of the rubber characteristics, the results are also dependent on the roughness of the rubber [21]. When the rubber is rough, the results on smooth surfaces are much higher, so that it may be more difficult to determine which of the products are slippery when wet. When the rubber is polished with a fine lapping film, one can differentiate between products at the slippery end of the slip resistance spectrum, but the results may not reflect the typical traction that would be available to someone whose footwear heel and sole bear the normal scratches and other evidence of wear.

The revised Australian standards now require lapping film usage. Any consequent underestimation of the slip resistance might be acceptable for AS 4586:2013 when classifying new products and when obtaining a worst case prediction of long term slip resistance. However, the use of such a fine lapping film issome what inappropriate when assessing the slip resistance of existing floors to AS 4663:2013. Property owners and managers want a valid reflection of the slip resistance of the floor so as to determine its relative safety and to control the floor maintenance; not to have it prematurely condemned. Accident investigators also need to determine the traction that was available at the time of an accident. The use of highly polished rubber is unlikely to be appropriate in such situations, as it is unrepresentative of most soling materials. A logical approach would be to condition the rubber on the floor sample, as occurs with the SlipAlert device. Given that there may be a need for the use of standardised conditioning surfaces (as the roughness of the floor to be tested might vary considerably) it might be more appropriate to simply revert to the previously used P400 paper. P400 paper might be used in all circumstances except when seeking to differentiate between the slip resistance of very smooth tiles, when the lapping film might be available for use as a secondary measure.

Any multiplicity of testing would not simplify the situation for manufacturers, but some sales ultimately depend on fulfilling customer expectations. Given the legal requirement in Europe to ensure that products have appropriate levels of sustainable slip resistance, why not focus on testing that ensures compliance?

From a Building Information Management (BIM) perspective, it would be better to flag an acceptable level of expected long term slip resistance, establishing a basis for audits. From a specification perspective, having acceptedaction and limit values is infinitely better than complying with inflated requirement new product requirements, with inherent uncertainty as to the likely slip resistance loss, and when remedial action should be initiated.

While it might be perceived that the pendulum has difficulties with respect to the rubber test feet (sliders) that are used, this is not necessarily the case. Given the wide variety of footwear soling materials that are used and their range of characteristics, together with diverse soling geometries, any slider should not be expected to provide slip resistance data that characterises a broad range of footwear. Although the ceramic tile slip resistance results yielded by any tribometer or standardised footwear are only indicative, they may range significantly, depending particularly on the surface roughness of the shoe surrogate.

Many ceramic tile standard test methods have been based on old quality control procedures and do not necessarily produce useful metrics that enable them to usefully compare products in order to optimise selections. Many compliant results provide little indication of probable performance, particularly where a thin layer of vitrified material has been applied to 'unglazed' products to protect the surface. Consumers should benefit from soiling, staining and slip resistance tests being performed after single or multiple stages or types of accelerated wear conditioning.

While slip resistance is a complex area where much further research is still required, it is obvious that the need for sufficient safety throughout an economically reasonable working life cannot be satisfied by rebadging a slightly modified version of CEN/TS 16165 as an ISO standard. A modern sustainable approach requires the incorporation of appropriate accelerated conditioning procedures, as well as limiting the use of test methods to those surfaces where reliable results are generated. Ideally, the users (or manufacturers) of portable devices would work towards use of a single test foot material and its method of preparation, where other materials and methods of preparation might be approved for specific design purposes and/or recommended for incident investigations.

2.8. WILL THE DATA BE USED AS WE EXPECT?

This review has considered many aspects of slip resistance metrics, but one must ultimately consider how the data is likely to be used. It should be noted that the data for new tiles might be used contrary to expectations, particularly in areas where there has been no past history of usage.

AS 3661.1: 1993, the initial Australian slip resistance standard, used the wet pendulum test but noted that the inclining ramp test method may be more suitable for heavily profiled surfaces (now identified by the SlipSTD Consortium as the upper level of Group 3). When the ramp test methods were included in AS/NZS 4586:1999, it was expected that architects would predominantly specify on the basis of the pendulum. However, since merchants have promoted the use of imported European tiles where the R classifications were available, specifications have increasingly been based on ramp classifications. It should be noted that much of the published data has related to a somewhat different earlier batch of tiles. This has caused many problems, particularly when the installed tiles have been discovered to have much less than the recommended level of slip resistance (according to the pendulum), such that the new tiles never complied with the HB 197 recommendation. Since the pendulum is always used for in situ measurements, pendulum based specifications tend to trump ramp based specifications.

The Institute of Access Training Australia (IATA) has just released 'The Why's' of Access Handbook [22], as a simple guide to understanding the rationale behind the mandatory Australian Standards for Access and Mobility, which require slip resistant internal and external accessways. The IATA Handbook states "surfaces that are not likely to become wet are to have a minimum slip resistance rating of R10"; "surfaces that are likely to become wet due to rain are to have a minimum slip resistance rating of R11"; and "two adjacent surfaces do not have a differential in slip resistance greater than R3, as this can cause a gripping hazard and cause people to stumble. For example, it is not advisable to use R13 or higher 'R' rating for Tactile Ground Surface Indicators adjacent to terrazzo flooring or similar flooring products that have lower 'R' ratings". Although the example would seem even more nonsensical if the stipulated R10 product is used, why have they specified in terms of a test method that was devised for industrial conditions where people are wearing safety footwear? Since HB 197: 1999 recommends appropriate levels of slip resistance for commercial areas, and a gradual transition through ramp and pendulum classifications for adjacent surfaces, why did IATA fail to reference the relevant guidance? The IATA Handbook could have referenced the HB 198: 2014 guidance for the wet, dry and transitional areas of public buildings, in terms of either the wet pendulum test and/or the oil-wet inclining platform test, but IATA has chosen to specify R11 and R10, when the Standards Australia slip resistance committee advised R10 and R9.

A Summer Foundation report [23] "New housing options for people with significant disability" recommends a minimum 45 BPN for internal wet residential bathroom areas and 55 BPN for external use. Although this was based on a superseded standard with P400 preparation of test feet, the failure to refer to class W or class P4 implies that this is a recommendation for in service performance (after some slip resistance has been lost). This guidance was developed from advice provided by safety consultants, where the HB 197 recommendation of 35 BPN for bathrooms in hospitals and aged care facilities was (counterproductively) increased to 45 BPN "to cater for the anticipated increased independence in apartment bathrooms by our tenants".

It is frustrating for standards developers to have contributing organisations thwart the development of guidance, and to see other bodies ignore such guidance. While there are several vested interests, it is unfortunate when progress is limited by short sightedness, with unrecognised victimisation of the intended beneficiaries.

2.9. IN CONCLUSION

The SlipSTD Consortium provided a straightforward means of differentiating between the surface texture and slip resistance function of tiles. It also identified some limitations of the slip resistance test methods, such that each test method should only be used on tiles that have suitable surface characteristics.

In order to reduce the environmental footprint of ceramic floor tiles, it is imperative that they provide sustained slip resistance, such that the public health injury burden might also be reduced. In order for architects to select appropriate products for a specific application, manufacturers must ensure they are tested rigorously in such a way as to demonstrate that they are fit for purpose.

At first glance it might have seemed that the addition of the ANSI A137.1 (BOT 3000) DCOF AcuTest to the CEN/TS 16165 test methods would have provided an expedient political solution for establishing ISO slip resistance test methods for ceramic tiles. However, solely adopting these five test methods would betray both the needs of the public and the long term interests of the ceramic tile industry.

Some merchants already recommend tiles that will have adequate slip resistance at the end of an economically reasonable working life, as long as they are properly maintained. Such recommendations and the existing test methods could and should be improved.

ISO/TC 189 WG 10 faces a colossal task. It needs to address the myriad issues that have historically confounded the tile industryand the slip resistance fraternity. The UK Slip Resistance Group is hosting an international conference in London in early October 2016 under the auspices of the International Ergonomics Association's Technical Committee on Slips, Trips and Falls. ISO/TC 189 WG 10 should seize such opportunities to discuss the issues and develop progressive solutions collaboratively. For example, can we identify a rubber test foot material and determine the most appropriate form of preparation that might be used in all the tribometers? Can we agree upon accelerated wear conditioning procedures that could be affordably adopted by test houses? Can we initiate international agreement on appropriate action and limit values?

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