



Slip resistance testing - Zones of uncertainty

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This paper considers recent and current potential developments in the international standardisation of slip resistance. It identifies some limitations of the wet barefoot ramp test, such that changes should be made if it is to be more widely used. It also identifies some limitations of the new European SlipSTD Publicly Available Specification, such as insufficient allowance for the deterioration of slip resistance as tiles inevitably wear.

Keywords: slip resistance, standards, test methods, surface roughness

Ensayo de Resistencia al resbalamiento - Zonas de incertidumbre

Este trabajo considera los desarrollos recientes y potenciales que hay en la actualidad en el desarrollo de las normas internacionales sobre la resistencia al resbalamiento. Identifica algunas limitaciones del ensayo de la rampa para pies descalzos en húmedo, para que se realicen cambios, si se va a usar de forma más extendida. También identifica algunas limitaciones de la nueva Especificación Europea Públicamente Disponible SlipSTD, como la falta de tener en cuenta adecuadamente el deterioro de la resistencia al resbalamiento de las baldosas a medida que inevitablemente se vayan desgastando.

Palabras clave: resistencia al resbalamiento, normas, métodos de ensayo, rugosidad superficial

1. INTRODUCTION

The lack of international standards for the slip resistance of ceramic tiles has been a continuing source of frustration. Architects want to be able to specify appropriately slip resistant tiles simply: they know that building owners want tiles that retain their aesthetics and can be easily maintained without extensive cleaning.

Specification of slip resistant products has been simplest in Germany, thanks to the explicit detailed guidance in the employers' liability insurance association BGR 181 (October 2003) regulations, which require that work areas have floor coverings of a specified slip classification (R9 to R13). There are similar requirements and guidance for (class A to C) floor coverings in wet barefoot areas (GUV-I 8527 regulations, July 1999). However, the relevant oil wet and wet barefoot slip resistance tests, DIN 51130:2004 and DIN 51097:1992, use an inclining ramp and can only be carried out in a laboratory. A lack of the necessary calibration boards has led to a testing monopoly and there are no established procedures for determining the probable future slip resistance of worn tiles.

Slip resistance is typically achieved through the surface roughness of the tile or by means of relief-type profiling. However, slip resistance is also very much a function of the footwear worn and any contaminant that is interposed between the tile and the foot. Just as there are different types of footwear that are more appropriate for certain types of contaminants, there are some types of slip resistance tests that are more relevant to specific situations.

The wet barefoot DIN 51097 ramp test is obviously proper for wet barefoot situations. The oil wet DIN 51130

ramp test, where the walkers wear heavily treaded safety shoes and engine oil is used, is more fitting for industrial and commercial situations where employers can control the footwear worn. Other tests are required for conditions where water is the most likely contaminant and there is minimal control over footwear and less control over public behaviour.

There is a particular need for tests that can be undertaken on site, whether to confirm that the installed tile has the required or stated slip resistance, as part of a regular audit program to verify that it still provides sufficient traction, or to investigate an alleged accident. The spectre of altered slip resistance is as real as human ageing: it is far more noticeable and momentous in some cases than others. This is the essence of the specification dilemma: how does one ensure that the tile will have satisfactory slip resistance throughout its planned service life?

This paper reviews some recent and intervening global developments that may result in new standards or a Technical Specification, the compromise interim solution when committees are unable to develop harmonised standards.

2. REVIEW

At Qualicer 2000, Bowman asked "Where to next with slip resistance standards?" [1], and reviewed some of the legislative requirements that were and are (or should be) driving slip resistance standards. This was in the context where Australian standard AS/NZS 4586:1999, *Slip resistance*

classification of new pedestrian surface materials, had adopted three wet test methods (the pendulum, the DIN 51097 wet barefoot ramp, and the DIN 51130 wet barefoot ramp) and the (Tortus) floor friction tester (FFT) for dry testing. Furthermore, the companion Standards Australia Handbook 197:1999, *An introductory guide to the slip resistance of pedestrian surface materials*, provided slip resistance specification guidance (largely based on the German regulations). Singapore adopted the same test methods and some limited guidance in SS 485:2001. Israel has similarly adopted these test methods in IS 2279:2009.

At Qualicer 2002, Bowman [2] considered options for developing future slip resistance standards, with particular reference to adoption within mandatory building codes and enforceable occupational health and safety legislation. He also noted that the European Construction Products Directive (CPD) 89/106/EEC requires products to have adequate slip resistance at the end of "an economically reasonable working life".

In 2002, the publication of BS 7976, *Pendulum testers*, provided a specification for the pendulum, a detailed method of operation and a means of calibration, independent of the type of surface being tested. The pendulum had already been adopted for testing some types of surfaces and has since been further adopted in Europe. However, the failure to nominate a specific surface for preparing the moderate hardness CEN rubber (when testing natural stone to EN 14231:2003) has permitted higher results to be reported than if the BS 7976 lapping film or a P400 abrasive paper was used [3]. EN 14231 also permits the use of a narrow 31.8 mm slider over a 76 mm path length, when the specimen is too small to be able to conduct the normal test.

One of the difficulties of standards such as AS/NZS 4586, that incorporate multiple test methods or variations within a method, is that a product might receive multiple classifications, some of which will sometimes provide seemingly conflicting guidance.

The choice of rubber in the pendulum (or other slip resistance devices) will influence the results, as is shown

in Figure 1, where the products might soon be classified in accordance with Table I. Incorporation of the minimal P0 rating ensures that all products can be classified. The absence of a minimal ramp classification has sometimes led to the false assumption that a product without a classification has not been tested.

Products tested with the moderate hardness TRL rubber will often receive a lower classification than those tested with the high hardness Four S rubber. A 35 BPN result is equivalent to a 0.36 coefficient of friction, which is often regarded as representing a one in a million risk of slipping [4]. The UK Slip Resistance Group [5] also uses 35 BPN as the cut-off point between moderate and low slip potential.

Figure 2 shows the effect of preparation of the slider. Those results that fall well below the line or zone of equivalent results indicate that use of the P400 abrasive paper can overestimate the wet slip resistance of smooth surfaces. AS/NZS 4586 will be adopting use of the BS 7976 lapping film for preparing the rubber slider when testing smooth surfaces (with an Rz roughness of less than 20 microns). This will result in several products receiving a lower classification, with most class Y products falling to class P1, and with many class X products falling to P2 or P1.

Figure 3 shows that there is poor correlation between the existing AS/NZS 4586 classifications. It can be seen that class R10 products vary from class V to class Z, and class X products vary from R9 to R12. Silva et al [6] also found that there was poor correlation between the oil-wet ramp tests and pendulum tests with CEN rubber.

When AS/NZS 4586 adopts the lapping film preparation, many of the class X, Y and Z products in Figure 3 will shift to the left, such that the new P3 (old X) class might not contain any class R9 products, but class R10 would still contain class P1 to P5 products.

One consequence of the use of the lapping film preparation is that it extends the slip resistance range at the less slip resistant end of the product range so that there is better discrimination between potentially slippery products. HB 197 is being rewritten to provide guidance that will enable

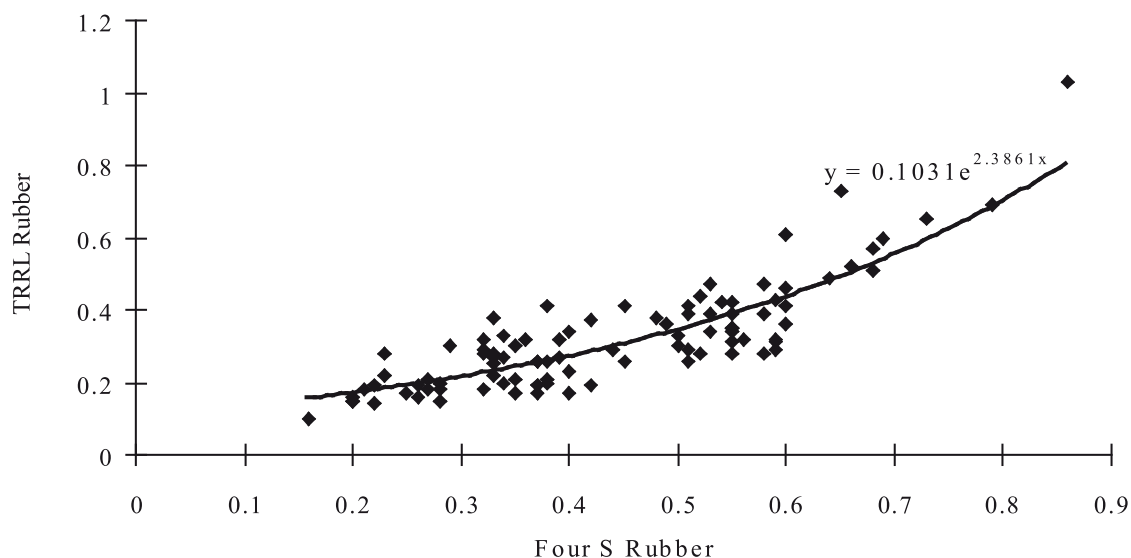


Figure 1 Comparison of pendulum results for 95 tiles when tested according to AS/NZS 4586, with the Four S and TRRL rubbers (expressed as coefficients of friction).

TABLE I. POSSIBLE NEW PENDULUM CLASSIFICATIONS FOR AS/NZS 4586:2010

Possible new classification	BPN range, Four S rubber	Existing classification	BPN range, TRL rubber	Existing classification
P0	< 12	Part of Z	< 12	-
P1	12 – 24	Part of Z	12 – 19	-
P2	25 – 34	Y	20 – 34	-
P3	35 – 44	X	35 – 39	-
P4	45 – 54	W	40 – 44	W
P5	>54	V	>44	V

the reclassified products to be more appropriately used. Class P1 products might be used within **dry areas** (areas in which appropriate control measures ensure an area remains clean and dry when in use). Class P0 products should not be used in dry commercial areas, such as supermarket aisles.

Class P2 products might be used in **transitional areas** (those areas that are intended to be kept dry, such as by the provision of design features (awnings, drains, mats, air locks etc.) appropriate to the physical location, climate and general exposure to water; and as maintained in a dry and clean condition by the facilities manager).

Class P3 products might be used in **wet areas** (areas that are not defined as a dry or transitional area, which may be either constantly or intermittently wet or otherwise contaminated). Class P4 or P5 products would be more appropriate in many external, commercial and industrial situations, particularly in locations where strenuous activities are likely to occur, or where viscous contaminants are present, such that enhanced slip resistance is required.

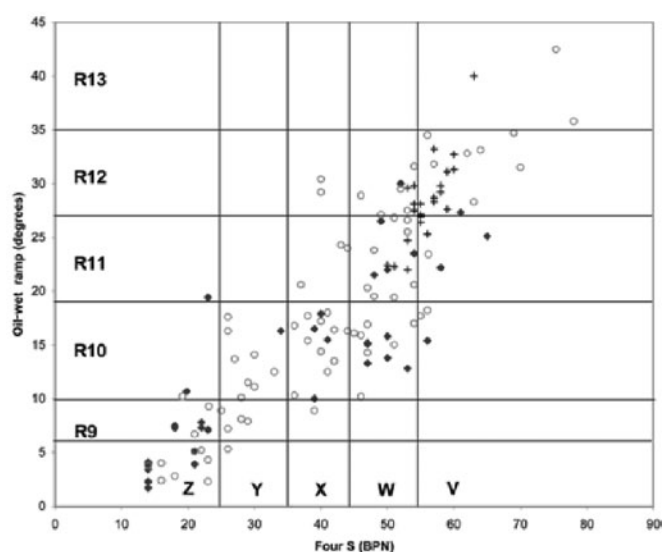


Figure 3 A comparison of oil-wet ramp and wet pendulum slip resistance results for some glazed (◆), porcelain (○) and terracotta tiles (+), where the Four S rubber test foot was prepared with P400 paper.

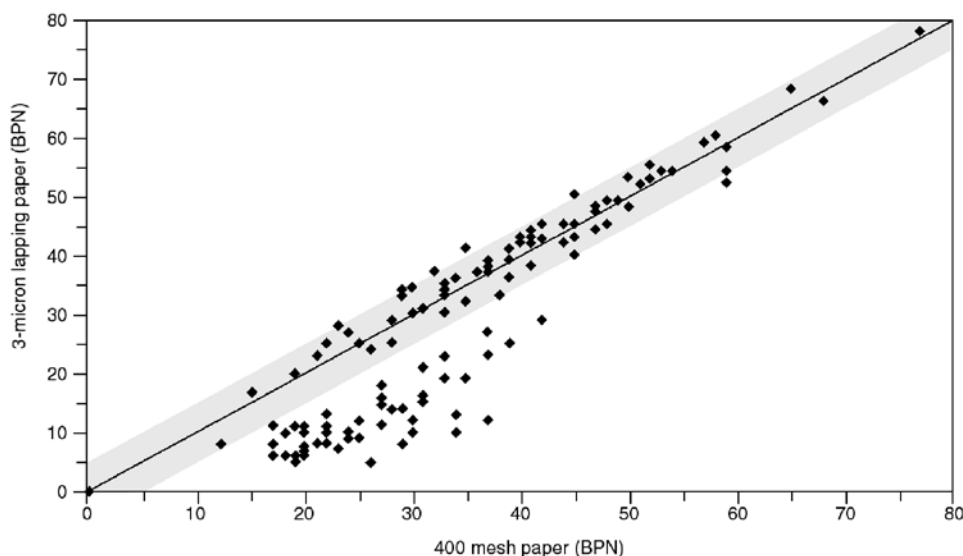


Figure 2 Results obtained for some ceramic tiles and stone, where the Four S rubber was prepared either on P400 abrasive paper or a 3 micron lapping film.

3. AN ABRASIVE TRUTH

At Qualicer 2004, Bowman [7] stated that "The need to predict the slip resistance of worn products will be a major driver. The need for accurate assessments of available traction will be another important influence. An associated research goal will be the development of process control equipment that assesses whether tiles have acceptable levels of slip resistance as they exit the kiln. This might be achieved by a suitable packaging of optoelectronic measuring systems and intelligent software, but is ultimately dependent on the ability to distinguish between the available traction provided by closely related surface textures. This ability will lead to the improved design of slip resistant surfaces that are relatively easy to clean".

Bowman et al [8] had been using the ISO 10545-7 surface abrasion test to prepare worn areas on tiles to assess how their slip resistance may change with wear over time. The slip resistance has been assessed using a laboratory based SATRA STM 603 device¹ since it can make measurements on the small (80 mm diameter) abraded surface. The accelerated wear procedure that Strautins has developed using a linear motion washability and wear tester [9] yields an area of sufficient size for pendulum testing.

Strautins has found that the slip resistance tends to drop rapidly during the first 100 abrasion cycles, such that all products should be exposed to at least this level of abrasion if they are to be used in low traffic private residential locations. While the slip resistance of slip resistant products may continue to slowly decrease, the amount of slip resistance lost in the first 1000 abrasion cycles will be much greater than any subsequent loss. This thus makes 1000 abrasion cycles a sensible requirement for assessing the probable slip resistance of products that might be used in high traffic situations. In some industrial situations it could be sensible to conduct the abrasion procedure using a lubricant other than water, to determine if there may be a synergistic chemical effect due to the nature of the expected contamination. It is also sensible to consider slip resistance tests with the expected contaminants where these are known.

The current (Australian) Natspec slip resistance performance design note [10] advises "Reports have emerged of instances of ceramic tiles, selected for having a classification of minimal notional contribution to the risk of slip, which, over a short period of time, deteriorated to such an extent that they were re-classified as potentially being a major contributor to the risk of slip. Accelerated wear testing, now available, may provide a useful indicator of the potential reduction in slip resistance over time. This process involves subjecting the floor sample through a number of cycles of wear in conjunction with wet pendulum testing. The number of test cycles may vary with the organization performing the test. Since pedestrian surfaces react differently to various wear mechanisms and exposure conditions, there is no single accelerated wear test method that will reliably apply to all materials and situations".

Although there is no officially standardised test procedure, architects are being advised to go beyond the draft AS/NZS 4586 standard in order to demonstrate due diligence.

In such circumstances, they should be seeking to confirm that the slip resistance will be at least 35 BPN for horizontal surfaces, and commensurately greater for sloping surfaces. Although the draft standard makes provision for determining the slip resistance after any mandated accelerated wear test procedure, it still requires the same classification procedure. Accepting that the existing HB 197 guidance is based on an understanding that the slip resistance of products will decrease in service, the 2010 revision of HB 197 will need to be provide some further guidance for products that have been subjected to an accelerated wear test procedure.

Although Strautins' work has shown that pendulum results will change rapidly after mild abrasion with abrasive pads, there has often been minimal, if any, discernible change in the Rz surface roughness of the same specimens. The observed loss of slip resistance may be due to a change in the surface roughness, but the Rz roughness is only one of several roughness parameters. The British Health and Safety Executive [11] appear to have placed undue reliance on the ability of Rz roughness measurements to conduct slip resistance safety audits.

Chang [12] identified the average of the maximum height above the mean line in each cut-off length (R_{pm}), the arithmetical average of surface slope (D_a), and the kernel roughness depth (R_k), as the three types of preferred surface microscopic geometric features for a higher friction. Chang concluded that although surface roughness was clearly important in determining slipperiness, there was still insufficient information to establish a safety criterion based on surface roughness measurements. Chang et al [13] also found that the surface parameters D_a , R_{pm} , R_k , R_{3z} and R_a had a stronger correlation with the transition friction than other parameters.

4. EUROPEAN DEVELOPMENTS

The European Construction Products Directive (CPD) 89/106/EEC requires products to have adequate slip resistance at the end of "an economically reasonable working life. Although this requirement should logically be driving the slip resistance research, such work is not readily evident.

In Europe, prCEN/TS 15673:2007, *Determination of the slip resistance of pedestrian surfaces – method of evaluation*, a draft technical specification, included wet and dry pendulum tests, a wet barefoot ramp test and an oil wet ramp test. It is understood that the final technical specification might include other devices such as the GMG 100 and the SlipAlert.

It is understood that the final European technical specification may adopt a modified version of the German **wet barefoot ramp test**, where:

1. The tiles for the three standard calibration boards are defined in terms of Rz surface microroughness ranges. Such a sole criterion would not seem to guarantee the uniformity of the calibration boards.
2. The issue of the long-term wear of the calibration boards does not appear to have been considered.

¹ URL: <http://www.satrap.co.uk>.

3. There is no requirement for training of the walkers, but they must qualify to walk on the calibration boards at the start of each day.
 4. Where test boards are close in value to a calibration board, there will no longer be a requirement for a direct comparison between the test and calibration board.
 5. The type of neutral wetting agent is not specified, even though sodium lauryl sulphate is a non-proprietary chemical that is commonly used.
 6. The requirement to stop using the test fluid one hour after its preparation has been removed.
 7. There is no control on the temperature or viscosity of the test fluid.
 8. There is no control as to any recirculation of the test fluid, such that a small quantity of water (and wetting agent) can be mixed and then continuously recirculated throughout the duration of the testing, which could last all day.
 9. There is no requirement for grout joints in the tiled test boards, or allowance for grout joints, although the new calibration boards must be laid with the tiles butted together without any grout joints.
 10. There is no actual requirement that the test tiles be fixed to a board, but the test surface must be self-supporting. There is no definition of self-supporting, but there should probably have been a statement requiring that the finished test surface provide a dimensionally stable walking surface that remains steady and firm (without any movement of the specimens relative to one another) during the test procedure. Ceramic tiles may be self supporting, but unfixed tiles can move when walked on if they are not sufficiently flat, large and capable of interlocking.
 11. Walkers must maintain an adequate rhythm, where a metronome set to 144 beats per minute has found to be a suitable pacemaker. However, other than requiring the walkers to be able to give acceptable results on the verification boards at the start of each day, no guidance is provided on the selection of walkers, their training, or a broader mandatory compliance qualification.
 12. The traditional A, B, C classifications will be replaced by (roughly equivalent) new B1, B2 and B3 barefoot area classifications.
 13. Products that have a corrected mean acceptance angle of less than 12 degrees will not receive a barefoot area classification.
5. Covert coaching of walkers during testing of the calibration boards.
 6. Loosely laid uninstalled tiles have moved relative to one another as they have been walked on during the test. There has certainly been a problem with smaller thinner tiles and with tiles that do not have a completely flat back surface.
 7. The presence or absence of grout joints (and grout on the face of tiles adjacent to grout joints).
 8. The use of silicone sealer in grout joints.
 9. Wear or contamination of the calibration boards – there are no requirements for their cleaning, nor is any guidance provided on how the boards should be maintained.
 10. Conducting the 'repeat' walks on the calibration boards at the start of the testing, such that there is a long interval between testing the calibration boards and the test boards, during which time the test conditions may have changed, or the walkers may have become tired or developed sore feet. Such 'repeat' walks are required by DIN 51097 where test boards are close to the calibration boards, but there is no specific requirement as to the timing of them.

Some profiled and abrasive test boards can be painful to walk on. While the test persons condition their feet in water and keep them wet throughout the testing phase, the state of their feet might vary during long test sessions (particularly when testing is conducted infrequently due to a policy of stockpiling of the samples, in order to maximise the financial returns by increasing the ratio of time spent walking on test boards as opposed to calibration boards). Any removal of skin during the walking results in a changed physical condition. A mandatory ten minutes soaking of feet conditions walkers' feet to water exposure prior to any walks, but the feet are not subjected to a controlled abrasion process. Any fatigue of the walker represents another variable.

The DIN 51097 test method does not have a requirement that walkers provide results on the calibration boards that are within set limits. This seemed most sensible in that, unlike footwear, their bare feet cannot be standardized in terms of profile and hardness. Their feet are 'conditioned' by being soaked in water for at least ten minutes prior to the test, but the condition of their feet can change during the course of walking trials when walking on abrasive surfaces. Their feet may also become quite sensitive if walking on some types of severely profiled surfaces. However, there is no discomfort clause requiring walkers to stop when the walking causes distress. Although such a clause could be difficult to write, walkers might still feel pressured to complete the testing. Since few pedestrian want to walk on surfaces that cause pain, it would be sensible to include a clause that requires walkers to report surfaces that are painful to walk on.

Recruitment of suitable walkers is not a simple task, as there may not be too many candidates for what is essentially a part time activity. Ricotti et al [15] compared the slip resistance of many commercial floor coverings and found that the ramp test can differentiate materials. However, since it produced different results depending on the test person involved; its repeatability could be seriously questioned.

Ricotti et al [15] plotted the results for four test persons for 24 of the 36 materials. They did not publish any results

Past experience [14] suggests that problematic results may have been due to:

1. Progressive contamination of recirculated water during the testing.
2. A change in the water temperature during the course of the testing.
3. The permitted usage time for the test fluid was exceeded.
4. Walkers 'learning' the slip resistance of the calibration boards, in that they have become conditioned to achieving the required results.

for the A, B and C calibration boards, and it has not been established whether or not these were used (but they have not been commercially available for several years). In the majority of the samples, the mean value for at least one of the walkers deviated by more than 2 degrees from the mean. However, since it was possible to find several samples where these four walkers were within 2 degrees of the mean, let us assume that these might have been calibration boards that verified that the walkers were competent to walk. On another test sample, the maximum difference between the test persons with the highest and lowest mean result was 13 degrees where the mean results for the four walkers were approximately 19.5, 10.6, 7.2 and 6.5 degrees, with a sample mean of 11.2 degrees. If one were to abandon the direct comparison with calibration boards, and any two of the four 'verified' walkers above were selected, the mean result for the board would vary from 7 to 15 degrees, assuming that they all achieved the same mean results when they repeated their walks. The results of Ricotti et al can be used to demonstrate that walkers can rank the wet barefoot resistance of boards differently.

Walkers who readily qualify for walking on the oil-wet calibration boards, have often deviated significantly from the nominal values for one or more of the wet barefoot calibration boards [personal observation]. This may relate to the condition or sensitivity of their feet, rather than their ability to walk in a particular fashion.

Consider that products which obtain results of 17.4 and 17.6 degrees might be classified as class B1 and B2 respectively, even though there is unlikely to be any significant difference in their wet barefoot slip resistance. Conversely, there should be a significant difference in performance between B1 and B2 products that yield results of 11.6 and 23.4 degrees respectively. Reporting of the mean acceptance angle in product literature should be a mandatory requirement so that specifiers can make better informed decisions. Under DIN 51097, it is still quite possible to classify a product with a mean of 26 degrees as class B (rather than class C) if the walkers have assessed the C calibration board at 27 degrees.

The DIN 51130 oil-wet ramp procedure uses the calibration board results to 'correct' the results for the test boards. I initiated a project to similarly 'correct' DIN 51097 results. The raw results for a few hundred products that had been wet barefoot tested over a number of years were entered into a database, together with the associated results for the DIN 51097 calibration boards. This led to some results being amended by a couple of degrees, but not to any changes in classification. This is not surprising in that the test boards had been directly compared to the calibration boards. Where there had been anomalous conflicting results relative to a calibration board, my policy had been to use multiple walkers. Associated research activities had also led to multiple walks on several samples. Preliminary analysis of such multiple walk data again supported the use of the trialled correction procedure to determine the ranking of products and to assign a meaningful corrected angle. Unfortunately, the electronic database files and all the associated printed material for this correction procedure were maliciously destroyed before the work could be written up for peer review and publication. However, several international laboratories could make similar data available for analysis by a student.

When the pendulum is used, the final step is always to check whether the zero setting is still correct. Where walkers

test several sets of tiles on a given day, they should logically be required to demonstrate that they are still within two degrees of the known calibrated value for each of the verification boards. However, if they are not within the acceptability range, this leads to a problem in determining which, if any, of the day's test results were valid (with the associated financial implications). This situation can be avoided where the test method permits a direct comparison with a calibration board. However, this would require the use of calibration (verification) boards that yield results of 12, 18 and 24 degrees.

Given the commercial unavailability of wet barefoot calibration boards over the last ten years, one must ask why the Germans have been unable to find replacement calibration (verification) boards that yield results of 12, 18 and 24 degrees. Since results are rounded to the nearest degree, this would not have seemed to be too difficult a task.

Both the wet barefoot ramp test and the oil-wet ramp test have requirements for a minimum surface area of 100 cm x 50 cm, even though the supplied calibration boards have used 150 x 150 mm tiles and thus been somewhat smaller. The use of a wider ramp where two 40 cm wide boards could be laid side by side would allow a direct comparison of the boards without the boards being too narrow to comfortably walk on. A test board that is 120 x 40 cm in size would allow more tiles to be walked on during a test than a 100 x 50 cm board. It is the least slip resistant tile among those on the test board that should determine the slip resistance of the sample, whereas with other tests, the slip resistance is usually the mean of the sample. Any tiles that are used on calibration boards need to be very consistent in their slip resistance from tile to tile, as well as over time (if wear or contamination of the boards occurs).

It is understood that the final European technical specification may adopt a modified version of the German **oil wet ramp test**, where:

1. The existing DIN 51130 calibration/verification boards will be used, although there are no boards commercially available, so that testing will be restricted to laboratories that have boards, until new boards are identified and become available.
2. New footwear will be used. Uvex Athletic 9452/9 shoes will replace the Lupos Picasso shoes (that replaced the Bottrop boots in 2004).
3. No guidance is given as to when the shoes should be replaced due to wear of the treads, but unlike DIN 51130 the sole shall be thoroughly abraded using an orbital sander fitted with P400 silicon carbide abrasive paper "before first use". It is not clear whether this is to be done only when the shoes are new, prior to daily verification testing, or perhaps when the soles appear to have been affected by testing on a particularly abrasive surface so that the sole no longer has a consistent, even, reproducible finish over the entire surface.
4. There will be a new series of work area group classifications W1 to W5, to correspond to the existing R9 to R13 classifications, but there will be no W0 classification to indicate a product that has been found to have a mean overall acceptance value of less than 6 degrees.

- It will be necessary to determine the direction of lowest slip resistance by testing the flooring, if the slip resistance differs depending on the direction of walking. While this might most sensibly be accomplished by using another test method such as the pendulum, this requirement presumably only relates to testing tiles in two or three orthogonal directions and perhaps the diagonal direction.

When considering the need to replace the standardised Bottrop footwear, Bowman et al [16] found that the Lupos Picasso boots gave results that were about 0.3 degrees higher than the Bottrop boots. This was sufficiently close to justify their adoption in 2004, despite their difference in soling patterns. I am unaware of the results of any study that has been undertaken to justify the use of the Uvex shoes, although any production change to the standard footwear can require that a replacement shoe be found.

Sebald [17] considered the uncertainty of measurement of shoes from the same product range, and found that there was a high uncertainty of measurement associated with the EN 13287 slip resistance test for footwear. Sebald used a 2003 and a 2004 DIN 51130 Lupos Picasso shoe in his study, and obtained slightly higher results for the 2004 shoe. Sebald recommended replacement of the ISO 13287 ceramic tile and steel reference materials, where wear of the reference materials caused by the conduct of tests probably contributed to the uncertainty of the test measurements.

Bowman et al [16] also found that there was a slight difference between the use of new and used Bottrop and Lupos shoes.

Manning et al [18] found that the microscopic roughness of the footwear soling surface is a major determinant of slip-resistance on lubricated surfaces, such that nearly the entire grip on atypically smooth floors was due to surface roughness of the soling material. It is quite possible that some past oil wet ramp test results have been influenced by the nature of the soling wear induced by the previous test samples.

Sebald, [17] in his thesis "System oriented concept for testing and assessment of the slip resistance of safety, protective

and occupational footwear", studied the slip resistance of 54 types of safety footwear using the new ISO 13287 mechanical shoe method and the now superseded DIN 4843-100 ramp test method. The study also involved 8 types of calibration and reference floor coverings, and 12 other floor coverings, where measurements were conducted using the DIN 51130 ramp test, the pendulum tester, GMG 100, BOT 3000 and FSC2000, although all the instruments were not used for all the tests. Table II compares Sebald's results for the oil-wet ramp test with those of the manufacturers' data. Table II looks at some of the results that Sebald obtained. Sebald did not offer a reason as to why he found that five of the nine products had a classification that differed from that stated by the manufacturer. Sebald noted that the oil wet ramp test only considers the new condition of the floor using a boot that has mid-range slip resistance, and that conversion to the real situations in work areas may lead to major deviations. Sebald concluded that "Owing to the different parameters in the various methods for friction measurement, little scope exists for the transfer between the methods".

It is understood that the final European technical specification may adopt a modified version of the BS 7976 **pendulum test** for wet and dry slip resistance measurements where:

- The test can be conducted with either Four S rubber (also known as slider 96) or the relatively new CEN rubber (also known as slider 59), which is used in EN 14231 and was specified in UNE ENV 12633:2003, *Method of determination of unpolished and polished slip/skid resistance value*.
- The maximum permitted limit of wear of the test sliders will be (reduced to) 3.0 mm for the Four S rubber and 2.5 mm for the CEN rubber.
- There may be a requirement that laboratory testing be conducted at $20 \pm 2^\circ\text{C}$, even though many laboratories are set to $23 \pm 2^\circ\text{C}$ and $50 \pm 5\%$ relative humidity.

TABLE II. COMPARISON OF DIN 51130 RESULTS FROM TILES TESTED IN SEBALD'S STUDY

Covering	Manufacturer's data		Study result		Difference in degrees	Surface appearance
	Degrees	Class	Degrees	Classification		
F09	6.5	R9	5.0	None	-1.5	Smooth
F10	7.9	R9	2.4	None	-5.5	Smooth
F11	11.7	R10	10.3	R10	-1.4	Smooth?
F12	22.7	R11	27.4	R12	+4.7	Textured?
F13	25.8	R11V4	22.2	R11	-3.6	Profiled
F14	30.8	R12	28.5	R12	-2.3	Textured?
F15	30.0	R12V4	25.2	R11	-4.8	Profiled
F16	36.7	R13V10	32.8	R12	-3.9	Profiled
F17	> 40.0	R13V10	36.5	R13	≤ -3.6	Structured

4. Specimens may be tested as manufactured (unpolished) or after a polishing regime. Strautins' accelerated wear test [9] would presumably be considered to be a 'polishing regime' even though it will dull the surface of polished porcelain and some glazed tiles.
5. There is a requirement for testing small units, such that it is necessary to form specimens by bonding units together after first grinding each adherend side flat. This requirement presumably does not apply to mosaic tiles, where it is anticipated that some slip resistance will be conferred by the grout joint profiles.
6. The testing must determine if the slip properties of the flooring are isotropic, where it may be necessary to conduct several tests at different angles on profiled flooring.
7. A minimum of three tests should be taken. These should be measured not more than 400 mm apart to obtain the main value for a location. The number of new specimens that need to be tested is not apparent. However, a 'test' might consist of measurements made on adjacent areas of a single specimen in each of three directions (two orthogonal at 90° to one another and one diagonal) or a single measurement made on at least three specimens.
8. The number of test positions for a particular area of flooring depends on the size of the area and the degree of variability over that area found during testing. Test locations may either be selected at random, or site specific locations may be selected based on traffic patterns and cleaning practices such that they are likely to indicate the full range of variability. The report should state which sampling method was adopted.
9. Where appropriate, the report should define the location of the site, and a drawing should show the positions of the test(s).
10. There is no requirement to report a pendulum slip resistance assessment group, nor has any guidance been provided on developing any such classifications, or on the interpretation of results.
11. There is a daily verification procedure on float glass and a lapping film, the need for stable reference materials in the low/middle slip resistance area and the middle/high slip resistance area is noted. AS/NZS 4586 recommends the conduct of internal laboratory assurance programs using stable control specimens that are of a range of surface roughnesses and are typical of the materials that the apparatus is used for measuring. It would seem sensible that such specimens be suitably abraded such that further wear during testing is unlikely.
12. There is no explicit requirement to report the slope of on site measurements, nor any guidance on how to interpret test results obtained on sloping surfaces.

Since the pendulum test is based on a loss of energy principle, and no energy is lost when the slider is not in contact with the test surface, the requirement to find the minimum slip resistance on a profiled surface is largely a matter of minimising the amount of contact while keeping the slider in continuous contact with the test surface, so that the slider does not swing into voids between the profiles (or the joints between tiles) before making violent recontact.

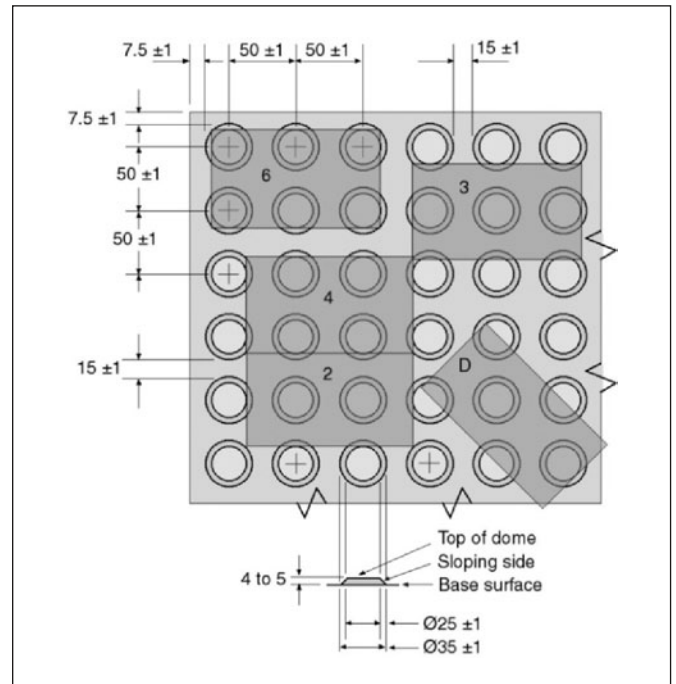


Figure 4. Example for ceramic warning tactile ground surface indicators.

However, how does one measure difficult materials such as stair nosing treads? These might have a rounded nosing, where the slip resistance of that rounded leading edge can be the critical concern. If the same finish extends onto the face of the tile, such flat sections could be cut out and bonded together for testing. A similar approach might be taken where profiled integrated nosings are cut off and bonded, whether they have recessed grooves at a regular spacing or a raised profile and an irregular spacing. However, since traffic on stairways is predominantly perpendicular to the nosing, should the reporting be principally based on this single direction in the normal flow of traffic? Where nosings contain an abrasive strip in an aluminium extrusion, does one measure the composite product or just the abrasive material? There seem to be many test houses that are keen to undertake the testing, where few are prepared to provide definitive interpretation as to the slip resistance that the product will provide.

Figure 4 and Table III provide the results for testing of some ceramic warning tactile ground surface indicators

TABLE III SUMMARY OF TEST RESULTS FOR A WARNING TACTILE GROUND SURFACE INDICATOR

TGSI orientation	BPN	
	Four S	TRRL
6 dome tops	56	48
4 dome tops	50	35
3 dome tops	49	44
2 dome tops	42	32
4 domes (diagonal)	77	65

TABLE IV SLIP RESISTANCE REQUIREMENTS FOR THE SPANISH TECHNICAL BUILDING CODE

Slip resistance	Class	Examples of usage in the Spanish Technical Building Code
$R_d \leq 15$	0	(Unregulated areas of private residences)
$15 < R_d \leq 35$	1	Interior dry public areas with a gradient of less than 6%
$35 < R_d \leq 45$	2	Internal wet areas: external entrances, bathrooms, kitchens
$R_d > 45$	3	External areas; garages; commercial kitchens; swimming pools

(TGSIs). Standards Australia Committee BD-094 considered that the result over 6 dome tops gave the best indication of the ‘true’ slip resistance of the unit. Some TGSIs are particularly difficult to test using Four S rubber, as the results may vary widely. The severe impact damage (gouging) that occurs to the non-proper surface of rubber sliders during such slip resistance testing indicates that the discontinuous nature of the surface causes a mechanical interaction that does not occur when testing other surfaces.

However, which would be the most appropriate configuration in Figure 5 for testing directional TGSIs? Testing along a 76 mm length of a single rib, similar to orientation 3, with a narrow (31.8 mm) slider and using the F measuring scale would seem to be a sensible option, as this will provide the best indication of the contact made between the upper surface of the TGSi and the footwear surrogate. This would seem to be the purpose of the testing, rather than seeking a configuration that yields a minimum result. However, neither the draft European technical specification nor AS/NZS 4586 make allowance for any use of the narrow slider.

Measurements of discrete TGSIs, such as individual dots or strips, are even more complex, due to a lack of planarity. Some units may be slightly higher or lower than the others, and some may be at an angle. This will change the type of

contact and the effective contact area between the pendulum rubber slider and the bearing surface of the TGSIs. It may change the pendulum result but not the fundamental slip resistance.

All users of the proposed European technical specification would benefit from further guidance on the recommended minimum number of test specimens for adequate characterisation of new products and existing floors. While a larger sample size is more likely to indicate any variety within a batch, even if there is significant variation within individual specimens, the question has to be asked as to whether there is much value in testing ex-factory tiles if this provides a poor indication of their slip resistance in service.

The absence of pendulum group assessment values is pleasing from an Australian perspective as we do not want a second European P rating that would conflict with the proposed P0 to P5 ratings (given the French UPEC P2, P3, P4, etc, performance ratings for the indentation and rolling wheel load resistance of floor coverings).

Individual countries should be able to establish some type of mandatory slip resistance requirement, even if they have to select their own accelerated wear treatment to ensure safety in use. Some Spanish manufacturers are capable of undertaking Strautins’ accelerated wear test [9], and it is understood that

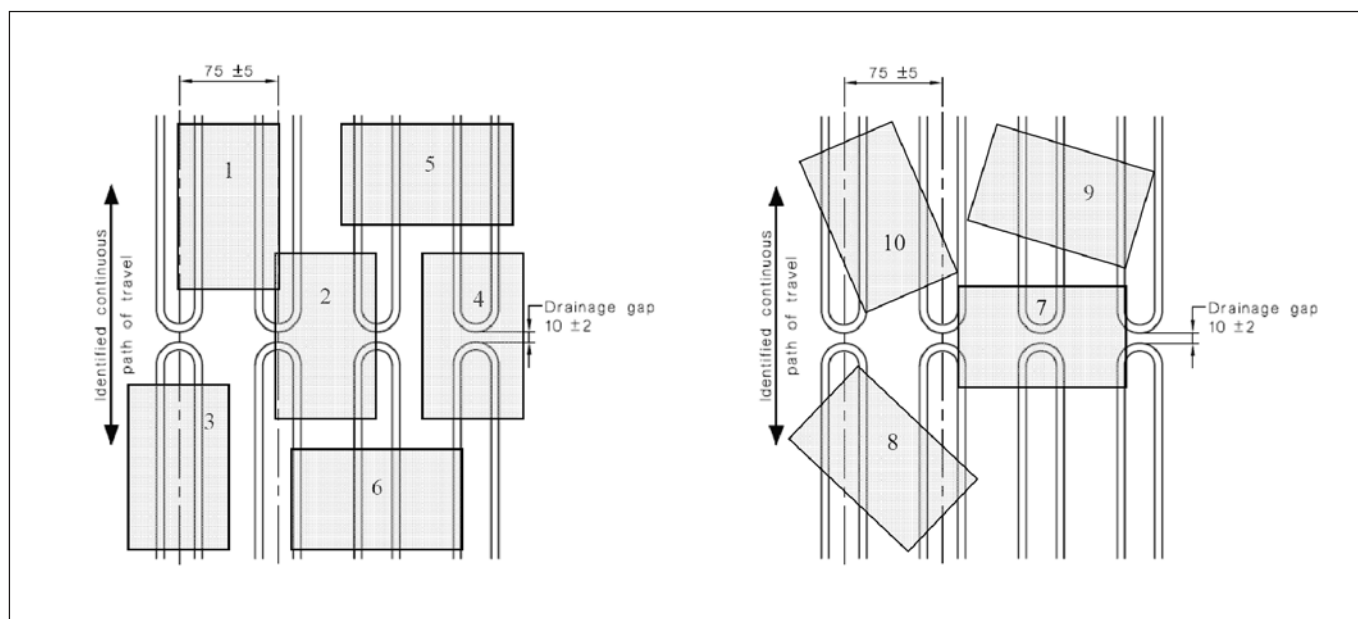


Figure 5. Some possible test location scenarios for 25 mm wide directional TGSIs

this has been useful in helping to develop products for specific projects.

The Spanish Technical Building Code established four classes of slip resistance based on the use of UNE ENV 12633:2003 and CEN rubber according to Table 1.1 of Basic Document, SU, Safety of Use, (March 2006). This is summarised in the following Table IV. However, it is probably only a matter of time until such national codes are overridden by a 'Eurocode'.

The UK Slip Resistance Group Guidelines [5] are based on the work of Harper, Warlow and Clarke [19]. This extensive study suggests that for unencumbered, reasonably active pedestrians aged between 18 and 60 a result of 36 BPN or above represents an acceptably low risk of slipping when walking in a straight line on a level surface. A result of 25 to 35 is regarded as representing a moderate slip potential, and results of 24 BPN or less a high slip potential. These Guidelines apply to both Four S and TRL rubbers, even though the use of both rubbers on a single surface might provide differing guidance, as is evident from the scatter of results in Figure 1.

BS 4592.0: 2006 requires a minimum Four S result of 39 BPN for slip resistant industrial flooring and a minimum Four S result of 55 BPN for enhanced slip resistant industrial flooring (for areas of strenuous activity). BS EN 7533-12:2006 recommends minimum values of 40 and 45 BPN respectively for **polished** pavers subject to pedestrian and vehicular use. Since the accelerated polishing test simulates the wear that might occur in service, the result provides some indication of the probable future slip resistance. However, whether or not the referenced polishing test or Strautins' abrasion test provides a better indication of wear can only be ascertained after the conduct of the necessary studies.

5. THE SLIPSTD EUROPEAN COLLECTIVE RESEARCH PROJECT

The SlipSTD consortium has published a SlipSTD publicly available specification (SlipSTD PAS) [20], where Annex B is a preliminary study on surface characteristics for foreseeable contaminated hard floor coverings. This publicly available specification has much to recommend it, where it proposes to classify hard floor coverings based on the likely presence of contaminants in the environment and in use.

The SlipSTD consortium recognises the different slip resistance methods produce results that are "hardly comparable and poorly relate to the micro and macro features of the floor covering surface". The project is using a different approach to assess the slip potential of hard floor coverings: it is measuring some surface properties and attempting to establish which surface features best correlate with slip resistance results determined by some established test methods (pendulum, wet barefoot ramp, oil wet ramp, and BCRA (Tortus) Floor Friction Tester). Given the poor correlation between the slip resistance results, and the existence of numerous defined two- and three-dimensional surface parameters, this is an extremely ambitious quest. Chang [12, 13, et al] is one of a number of researchers who have found some correlation between surface roughness parameters and a particular measure of slip resistance. However, those parameters that best correlate with the slip resistance of some products correlate poorly with

others. Trying to simplify innumerable observable facts and to convert complex multifactorial phenomena into sensible codes of practice is an extremely ambitious undertaking.

Despite a seeming lack of supporting evidence, and an acknowledgement that the simple measurement of a single roughness parameter cannot completely characterise a surface in relation to its slip potential, the SlipSTD consortium has recommended adopting the measurement of Rz with tactile two-dimensional devices as a routine (maintenance) parameter for monitoring in-use changes to hard floor coverings. Rz surface roughness can be measured quickly and easily, which enables it to be used by people who do not have a recognised portable slip resistance device such as the pendulum.

The SlipSTD PAS states "Wear and abrasion degrade all floor covering surfaces over a period of time. The rate of degradation depends on the installation environment and usage. There is no current standard or officially recognised test method that simulates surface wear and predicts service life for a floor coverings surface technical characteristic's, including slip resistance. Therefore, it becomes the duty holder's responsibility to establish a control plan to monitor the condition of the floor covering to determine the acceptability of its slip resistance. The control plan should take into account the environment, working conditions and any information derived from previous experience of using the flooring surface in question". I would not advise a duty holder to rely upon Rz surface roughness measurements to determine slip resistance acceptability.

Despite recognising the critical importance of slip resistance degradation, the consortium appears to have focused solely on the measurement of ex-factory ceramic tiles. There is a vital need to consider changes to the slip resistance of tiles and calibration boards.

The SlipSTD consortium has defined three groups of pedestrian surfaces according to surface features detectable by visual and tactile inspection and measurement of primary three-dimensional surface parameters Pp and Pk, the core roughness. This parameter basically describes the long term running surface after use has worn the top surface away. Parameters based on a recognition that wear will occur have an inherent appeal.

However, while three-dimensional surface measurements can be made in a few well equipped research laboratories, they have not commonly been made within the ceramic tile industry. Measurements of existing floors generally require either the removal of a specimen or the casting of replicas. The proposed groups may have tiles that exhibit anomalous slip resistance characteristics:

- **Group 1.** Smooth surfaces with $P_k < 50 \mu\text{m}$. Pedestrian surfaces within this group tend to be slippery when contaminated.
- **Group 2.** Non-profiled, essentially even surfaces with gritty touch with $50 \mu\text{m} < P_k < 100 \mu\text{m}$ and $90 \mu\text{m} < P_p < 200 \mu\text{m}$.
- **Group 3.** Profiled, textured or structured surfaces with $P_k > 100 \mu\text{m}$ and $P_p > 200 \mu\text{m}$.

The SlipSTD consortium has defined three classes of hard floor coverings that help to identify the available controls, including the choice of appropriate floor coverings, but do not restrict or impose on design or selection:

- **Class 1:** Hard floor coverings for internal pedestrian areas that are foreseeably clean and dry and are routinely maintained as such.
- **Class 2A:** Hard floor coverings for internal pedestrian areas foreseeably contaminated with water and/or dry contaminants.
- **Class 2B:** Hard floor coverings for internal pedestrian areas foreseeably contaminated with other liquid contaminants with viscosity higher than water, such as oil and grease.

Bowman and Bohlken [21] raised the possibility of real-time automated process control of slip resistance by combining a suitable packaging of optoelectronic measuring systems and intelligent software. This might be achieved using unfiltered data rather than derived parameters, where the extent of any deviation from the desired or acceptable surface features is established for specific individual products. The system might be based on differentiating between the profiles of acceptable and unacceptable specimens.

Simplistically, slip-resistant properties may be achieved through the tile's surface roughness, or by means of relief-type profiling, or their combination. Considering the wide range of existing slip resistant products, it may be easier to tailor solutions for individual products, than to try and find one solution (or a few solutions) that fits all. Sophisticated 3D surface roughness measurements may be useful for process quality control purposes, but slip resistance measurements are likely to be necessary for confirming the slip resistance of ex-factory products, the probable slip resistance of worn products, meaningful audits and the investigation of alleged accidents.

Bowman suggested [22] that since the SlipSTD European collective research project was seeking to understand the relationship between the surface characteristics of tiles and slip resistance, it should determine what surface changes occur during Strautins' accelerated wear test, thus promoting a better understanding of slip resistance issues for tile manufacturers, and allow them to improve the surface characteristics of tiles. Similar studies should also be made of tiles that have been exposed to pedestrian traffic and routine maintenance cycles.

6. CONCLUDING REMARKS

Architects know that some flooring materials are less durable than others and that the slip resistance may change in service. Barristers have argued that architects should not be expected to be slip resistance experts: they should not have to make detailed analyses of proprietary product data in order to determine whether a product is as slip resistant as it might initially appear to be. If it should be expected that the slip resistance will significantly deteriorate with time as a function of normal predictable wear, the manufacturer (or a standard that the manufacturer can use) should specifically bring this to the architect's attention.

One Australian legal firm has stated that no floor surface will ever be made available to the public in the condition that it was originally tested. This does not mean that floors cannot be sensibly specified where there is an expectation of the probable slip resistance throughout the intended design life.

There is increasing pressure to publish an Australian standard for an accelerated wear conditioning procedure: it is vital that products be selected on the basis of their likely in service performance rather than the illusion provided by results obtained on ex-factory products. This standard is likely to reflect the work of Strautins [9].

Various experiences with surface roughness measurements suggest that the current focus of the SlipSTD European collective research project on using some topographic and surface roughness characteristics for specifying hard floor coverings is optimistic. Slip resistance tests provide an actual measure, and the most appropriate tests can be chosen to assist the specification of tiles in particular locations. However, the use of optical topography measurements could productively be extended to studies of how the surfaces of tiles change in use, thus enabling the engineering of tile surfaces that will provide appropriately sustainable slip resistance.

The process of standardisation is continuous where decisions should be transparent. While drafts are constantly revised and incrementally improved, further optimisation is generally possible, even when we seem compelled to adopt temporary positions until further data becomes available.

There may be a European presumption that the evolving draft CEN/TC 339 Technical Specification will eventually become an ISO Technical Specification. While Australian interests would probably support such a proposition, there are several aspects that the Committee should further consider. Have the fundamental expectations of all the stakeholders been met? Will architects be able to specify products confident in the knowledge that they will be sufficiently slip resistant over their design life, without requiring an excessive maintenance regime? Courts require reliable measures of slip resistance rather than the measurement of surface parameters that might be impossible to interpret sensibly and definitively.

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