ASSESSING THE RELATIVE CONTRIBUTION OF CERAMIC TILES TO SLIP AND FALL ACCIDENTS

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INTRODUCTION

Slip and fall accidents are a significant problem given the frequency of their incidence and the magnitude of the associated costs[1]. Slips occur when the foot cannot achieve adequate effective contact or grip on the floor surface. This usually occurs when something has been spilt or when the shoe sole and floor are unsuited. This paper will consider aspects of assessing the relative contribution of ceramic tiles to slip and fall accidents.

Studies of several accident case histories reveal that slips and falls can be due to many factors. The primary factors include the characteristics of the tile laid; its condition at the time of the incident (reflecting both its degree of wear and the effectiveness of any maintenance program); the type of footwear being worn and its physical condition; the presence of any contaminant on the floor and its nature; the activity that the victim was undertaking; the physical and mental state of the victim at the time of the incident; the quality of the lighting or the degree of visibility; and any changes of level or slopes.

Forensic engineers must determine which factors are significant in any individual incident, and the relative extent to which each factor might have contributed to that accident. If two people were to slip and fall on the same floor, the causal factors could be quite different even though the floor is a common factor.

In cases of litigation, judges rely heavily upon Standards, Guides and local building regulations. One should thus consider how well any Standards serve the needs of the various vested interest groups, e.g. the public, property owners, manufacturers and forensic engineers.

[1]. ENGLANDER, F., HODSON, T.J. AND TERREGROSSA, R.A.: J. Forensic Sci., 1996, 41 (5), 733-746.

Tile manufacturers and suppliers logically seek compliance figures, and would accept one that is high enough to allow for a reasonable amount of wear and level of maintenance, if this is their sole contractual obligation. They are not too concerned with the test method as long as it does not disadvantage them. By contrast, municipal authorities and building operators and managers are more concerned with the in-service slip resistance over the design life of a facility. They are interested in portable testing equipment and the establishment of appropriate criteria for different types of environments. The forensic scientists are also interested in portable testing equipment, although its cost may be a major concern for many of the independent consultants. They tend to have a greater focus on the shoe material. They might argue that their client deserves compensation because the defendants failed to use a tile that was safe for someone wearing shoes with soles that had inherently poor slip resistance. Others might argue that it was not so much the shoe materials, but the design or condition of the sole and heel. Aspects of sole and heel design can be most effectively assessed using laboratory based equipment that allows relevant biomechanical issues to be considered.

This paper also briefly reviews the approach that has been taken in revising the Australia/ New Zealand Standard for the slip resistance of pedestrian surfaces, as this should provide a fairer assessment of the relative contribution to accidents than a simple pass/ fail criterion.

PRODUCT LIABILITY

Product liability laws vary throughout the world. This section, based on an American analysis[2], is intended to provide information of general interest. It cannot substitute for in-depth analysis of particular scenarios.

"Suppose your company manufactures ceramic tile that is sold in retail stores to consumers. Now, also suppose that a consumer purchases tile made by your company at such a store and installs it herself on the floor of her kitchen. Shortly afterward, her husband slips on the tile floor, breaking his leg. Might your company be sued by the husband claiming your company was somehow responsible for his broken leg?

Lawsuits resulting from alleged injuries suffered by those who use consumer products are known as product liability suits. Such legal actions have received a great deal of attention in recent years as their number has grown. A major effort has been launched in Congress to put some limits on the amount of damages that could be awarded and the time frame for instigating such suits.

Recently, a group of legal scholars extensively reviewed the subject and drafted what is known as the 'Restatement of the Law of Torts: Product Liability.' This restatement is designed to help lawyers and judges determine what the law is in the area of product liability and how it should be applied under changing conditions.

Those in the ceramic industry are not immune from such suits, and managers at all corporate levels need to be aware of their nature and potential.

Generally, if someone feels an injury was caused by a consumer product such as the

[2]. J.A. Calderwood; *Ceramic Industry*, October 1997, 27

ceramic tile on the floor mentioned earlier, they have to show that it was defective in some way to be successful in a legal action. It could be alleged that the product was defectively manufactured (e.g., a nonskid coating was left off the tile the now-litigious consumer purchased). The plaintiff may accuse the manufacturer of defectively designing the product (e.g., other tile manufacturers design the product with ripples to prevent skids; the defendant did not). There may be an allegation that the manufacturer did not supply adequate warnings about the product (e.g., the installation instructions did not explain the best way to apply it to the floor to avoid slips by those walking on it).

Basically, a producer of a product is held liable for personal injuries resulting from the manufacture of a defective item. The producer is liable if the product reached the consumer without a substantial change from the condition it was in when first produced. In other words, as long as the product was not materially altered from the time of its manufacture through its use by a consumer, the producer is liable for injuries caused by defects even if the product passed through the hands of numerous middlemen, such as retailers, before being used by the plaintiff.

Often an action for injury from use of a product will allege that the manufacturer was negligent in the way it tested the product. A producer has a duty to make products that are free from defects that raise an unreasonable risk of harm. This duty requires that products be regularly tested and inspected. This is especially important before a ceramic product is first marketed. It also means that the manufacturer needs to be aware of all tests that are generally accepted in the industry for the particular category of product. This can include, for instance, tests promulgated by organizations, such as the American Society of Testing Materials. Some companies hire outside laboratories to conduct at least final-stage testing to be able to refute later charges of corporate bias in testing.

Product inspection during the manufacturing process is also important in order to be able to deflect accusations of negligence. The product design and materials used may be safe, but if the product itself is improperly made, it may cause problems leading to an injury.

Product liability suits often name everyone in the chain of distribution as a defendant. This means the manufacturer, importer, distributor and retailer. Issues related to one party in the chain being responsible for indemnifying others in the chain will then arise. It is not unusual for retailers and others to insist on an indemnity clause in any contract for the purchase of goods, whereby the seller of the product agrees to pay any legal judgments against the retailer along with the retailer's legal fees if there is a product liability suit.

It may sometimes seem that a number of absurd product injury suits are filed (e.g., injury from a coffee spill at a fast food restaurant). Such litigation can be harrowing and time-consuming, but often plaintiffs eventually lose because the injury was simply too remote from the product's use. However, ceramic manufacturers need to always be vigilant that their products are designed and produced in a safe manner, or surely a suit will follow".

SLIP RESISTANCE TESTING

Calderwood's article[2] raises the question as to what is adequate testing for slip

[2]. J.A. CALDERWOOD; *Ceramic Industry*, October 1997, 27

resistance. An abundance of devices and test methods have been used to assess slip resistance. However, all the investigations to date have been unable to find a simple solution to the problem of determining the relationships between footwear and floors. As Rowland[3] has 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'

The absence of a universal solution is unlikely to be of much comfort to tile manufacturers, who must determine which test or tests they should use. It appears that there will be four test methods in ISO 10545.17 Ceramic Tiles: Determination of coefficient of friction. These are a self-propelled mobile apparatus described as a Floor Friction Tester (FFT); a static test method similar to ASTM C1028; the inclined platform (ramp) as used in DIN 51130; and the British Pendulum tester. While no manufacturer would want to use all four test methods, this may sometimes be necessary. In some countries, there are codes and regulations that must be complied with that stipulate the use of one or more of the above test methods. In recognising that some test methods sometimes provide misleading results, there is an obvious advantage in using more than one test method to characterise products. It is obviously preferable that the results should correlate well with subjective assessment of floors, and it should be noted that the FFT does not provide a good correlation with wet slip resistance[4]. Proctor[5] found that the FFT and the Pendulum were unsatisfactory for assessing the slip resistance of floors that incorporate a raised profile.

Despite Kime[6] and Proctor[5] stating that FFT coefficient of friction (COF) measurements should not be evaluated against criteria developed for use with other instruments, such evaluations still occasionally occur. Proctor stated that on wet floors using the Four S rubber slider 'a reading above 0.68 is required to ensure safety', significantly higher than the 0.4 value that is often used.

As Proctor stated 'The interpretation of the results of measurements of the slip-resistance of floors is very complex. It is clear that architects and flooring contractors need to be advised on correct interpretation... This information can only be supplied by the organisation responsible for carrying out the tests and should be included in the test reports'. However, in view of the complexity of slip resistance, it is not surprising that test houses are reluctant to volunteer unsolicited advice, given the potential litigious ramifications.

REVISIONS TO AS/NZS 3661

The joint Australian/ New Zealand Standard for the slip resistance of pedestrian surfaces is currently being revised. While the draft is still subject to change, it is interesting to consider aspects of some of the contemplated revisions. Part 1, 'Slip resistance of new pedestrian surface materials', has been prepared so that it can be called up by the

[3]. F.J. Rowland: *5th NOKOBETEF Conference on Protective Clothing*, 5-8 May 1997, Denmark.
[4]. G.W. Harris and S.R. Shaw: J. *Occup. Accidents*, 9 (1988) 287.
[5]. T.D. Proctor: *Safety Science*, 1993, 16, 367
[6]. G.A. Kime: J. *Occup. Accid.*, 1991, 14, 223

mandatory Building Code of Australia. It provides a number of ways for manufacturers to classify ceramic tiles and other flooring materials. Part 2, 'Guide to the assessment and reduction of pedestrian slip hazards', reflects a change in emphasis from measuring slip resistance to evaluating slip hazards, whereby a wide range of factors need to be considered. This more holistic approach can be used for planning new installations, for considering remedial measures in existing installations, as well as in forensic investigations.

AS/NZS 3661.1 will recognise four test methods: dry FFT; wet Pendulum; and the inclined platform according to DIN 51130 (slip resistance in industrial and commercial areas) and DIN 51097 (slip resistance in barefoot areas). The inclusion of these tests recognise that the ramp is suitable for evaluating the slip resistance of profiled floors[3]. The inclined platform is also considered to be more suitable for resilient surfaces. The inclined platform also has the advantage of two comprehensive German classification systems that mandate the level of slip resistance required in specific areas. The fact that these classification systems are controlled by the Central Office for Accident Prevention and Industrial Medicine (Main Organisation of the Trade Organisations) and the German National Accident Insurance Board provides an additional level of confidence.

Although these inclined platform tests are both German standards, it is interesting to note a difference in their approach. Since these test methods are based on a subjective assessment, both require the use of two human test subjects to walk on a separate set of three calibration boards and on the test tiles. DIN 51130 requires that each test subject does not deviate outside prescribed limits with each of the calibration boards. This standard uses a series of equations to calculate correction factors which are applied to the results. One thus obtains a precise final angle. DIN 51097 does not prescribe deviation limits. It requires that each test sample should be compared with the relevant classification tiles to determine whether the sample is, for example, as good as the A-covering, or better than the A-covering but not as good as the B-covering.

The deliberate use of two test methods (the inclined platform and the pendulum) that may provide conflicting indications as to the suitability of a product will no doubt give rise to some interesting situations. It is quite probable that Table 1 will be used to interpret the pendulum results.

Class	Mean Pendulum Four S rubber	Number (BPN) TRRL rubber	Contribution of the floor surface to the risk of slipping when wet
V	> 55	> 45	Very low
W	45 - 54	40 - 44	Low
X	35 - 44	-	Moderate
Y	25 - 34	-	High
Z	< 25	-	Very high

Note: It is expected that these surfaces will be more slip resistive when dry.

***Table 1**. Classification of pedestrian surface materials for wet slip resistance according to the Pendulum test.*

This table is a marked departure from that of the widely used Greater London Council (GLC) criteria given in Table 2, in that it recognises that the floor surface is only one of the potential causal factors in a slip and fall accident. It should also be noted that the GLC criteria were apparently based on a very limited number of results, and that measurements were being made both in the wet and the dry[7].

[3]. F.J. Rowland: *5th NOKOBETEF Conference on Protective Clothing*, 5-8 May 1997, Denmark.
[7]. Greater London Council (Architect's Dept): *Development and Materials Bulletin* 43 (2nd Series), 1971, Item 5.

Dangerous – 19 or below. This condition is quite unsafe and, where it exists, immediate action should be taken to replace or treat the surface to an acceptable standard.
Marginal – 20 to 39. The surface is below the recommended safe level and methods of improving the condition should be considered and carried out as soon as reasonably possible. Some remedial treatments have only temporary effect and will need to be repeated at required intervals; in the long term, the substitution of an alternative finish may be more economical. In the meantime, warnings should be given to all using the building that care must be observed.
Satisfactory – 40 to 74. As the consequences of a fall by the elderly are generally serious and frequently fatal, the slip resistance of floors, stairs and pavings designed for their use should be well within the 'satisfactory' range.
Excellent – 75 and above. This condition, though desirable in many situations, is required in certain special cases, such as railway platform edges and crowded public stairs.

Table 2. *Classification of pedestrian surface materials for slip resistance according to the Greater London Council using the TRRL soft rubber slider in the Pendulum.*

The use of both the Four S and the TRRL rubber in AS/NZS 3661.1 recognises that the TRRL rubber can provide better discrimination on rough surfaces, such as clay and concrete pavers[8], where such discrimination is required. However, when the GLC criteria are used, the soft TRRL rubber tends to class most smooth floors as marginal or unsafe. The Four S (Simulated Standard Shoe Sole) rubber is harder. When used in the pendulum test, this rubber was reported to distinguish the very rough floors at one extreme, put polished marble and smooth stainless steel at the other, and to divide the remaining floors in a very clear fashion[9]. At the levels of roughness normally encountered indoors (i.e. excluding pavers), the Four S rubber was reported to give greater discrimination than the TRRL rubber. Although the use of the TRRL rubber has been restricted to the higher slip resistance categories, V and W, it is evident from some of the tests that have been conducted, that the use of the two rubbers will sometimes lead to different classifications (Table 3 and Figure 1). One has to question whether the confusion that might arise from the use of two rubbers is justifiable, when the TRRL rubber is only being used to discriminate amongst highly slip resistant products.

	Classification of tiles using the Four S rubber				
TRRL based classification	Z	Y	X	W	V
V	-	-	-	2	11
W	-	-	2	9	1
-	9	24	18	18	1

Table 3. *Comparison of how the 95 tiles in Figure 1 were classified according to Table 1 when tested with both the Four S and TRRL rubbers.*

It is obvious that the shoe sole material will also have a significant effect. One might consider the situation of a glazed tile with a highly textured surface which has a Four S pendulum number of 40 (which just passes the current AS/NZS 3661.1 wet area requirement). However, when the tile is tested according to DIN 51097, it just fails to get an A classification. This indicates that while the tile may be suitable for some wet areas where shoes are being worn, it is inappropriate for barefoot areas such as public showers and pool surrounds, where a class B tile is required.

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[8]. James, D.I.: in *Clay Paving Bricks* (Proc. 44, The Institute of Ceramics), 1989, 49–60.
[9]. James, D.I.: *Polymer Testing*, 1989, 8, 9–17.

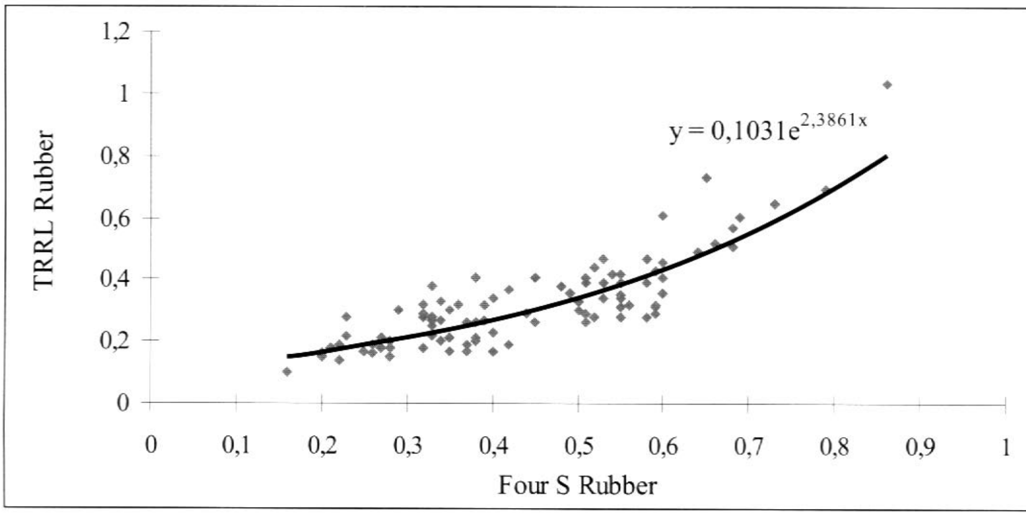

Figure 1. *Comparison of how 95 tiles were classified when tested with both the Four S and TRRL rubbers.*

There will also be anomalies when it comes to public commercial and industrial areas. The German regulations permit class R9 tiles to be used in retail stores, hospital rooms, sick rooms, entrances to buildings, corridors and stairs in administrative buildings, hospitals, banks, etc. There have been some instances where tiles with an R11 classification (required in areas such as commercial laundries and drink bottling rooms) have just failed the current AS/NZS 3661.1 wet area requirement, but would achieve the X classification in Table 1. There are other products that pass the current AS/NZS 3661.1 wet area requirement, that would also obtain an X classification, that have been associated with slip and fall accidents. This may reflect upon the victim's footwear, an alteration of the inherent slip resistance of the product due to wear or inappropriate maintenance, a contaminant other than water, or some other contributing causal factors. It certainly reflects upon the difficulty in wholly relying upon a sole number as a reliable indicator of the potential contribution of a tile to the risk of slipping.

This limitation has been partly recognised in the German system for classifying various commercial and industrial areas [ZH 1/571] where there are also volumetric displacement requirements for areas such as some catering, food processing and vehicle repair workshop areas. The volumetric displacement is a measure of the open space between the upper walked-on surface and the drainage level of highly textured or profiled surfaces. Volumetric displacement requirements allow for adequate sub-surface drainage or entrapment of spilt materials. AS/NZS 3661 is also adopting volumetric displacement requirements.

The British Health and Safety Executive (HSE) has been advocating surface roughness measurements as a secondary means of assessing the slip resistance of flooring materials. Harris and Shaw[4] concluded that a R_{tm} surface roughness of between 8 and 10 μm was required for walking in water wet conditions (R_{tm} measured over a traverse length of 4.0 mm which was split into five cut off lengths of 0.8 mm). More recent work has shown that the numerical value of roughness increases with an increase in the cut off length (to 8.0 mm) of the measurement[3], and that a measure of the roughness peaks above the datum line (R_{pm}) gave a better correlation for slip resistance with the DIN ramp test than the maximum peak to trough (R_{tm}) readings

[3]. F.J. Rowland: *5th NOKOBETEF Conference on Protective Clothing*, 5-8 May 1997, Denmark.
[4]. G.W. Harris and S.R. Shaw: J. *Occup. Accidents*, 9 (1988) 287.

alone[10]. This work indicated that, for enhanced slip safety in wet conditions, a minimum Rpm was required, of 8 μm for soft (resilient) floors and 25 μm for hard floors. It was concluded that both roughness and hardness should be considered when evaluating floor surfaces and footwear.

CSIRO has been determining and reporting the R_{tm} surface roughness over a 0.8 mm cut off length on its slip resistance website [http://www.dbce.csiro.au/pubs/slip]. Although surface roughness measurements may be very useful for products with homogeneous surfaces, they may also discriminate against products that have a heterogeneous surface. This is particularly so when the surface contains a limited amount of embedded particles that provide slip resistance, but which may not be included in the path of the surface roughness measurement. The surface roughness of such products may exhibit high standard deviations about a low mean.

FLOORING PRODUCT SELECTION QUANDARIES

The slip resistance characteristics of buildings vary enormously, depending on factors such as the activities carried out in the building, the cleaning methods used, and the types of footwear that are being worn. The activities that are conducted within a building are well covered by the German classification systems. Thus, use of the ramp test results simplifies the process of product selection. However, one area that may need to be considered further is that of entrance foyers. It may be more appropriate for class R10 or R11 tiles to be used, depending on the design provisions that are made for the exclusion of water. Another application that requires further consideration is that of stairs, where some convention is necessary to establish whether or not the relevant portion of a stair tread is slip resistant or not.

Slip resistance is only one of a number of criteria that must be considered when selecting a ceramic tile. Durability is obviously important, and it can be readily appreciated that the slip resistance is likely to alter as the surface becomes worn. The Clay Brick and Paver Institute anticipates that pavers will polish with wear and allows for an ultimate reduction of some 10 to 15 BPN units when the product is in service. However, the slip resistance of some glazed ceramic tiles will increase with wear. The Standard contains no requirements for slip resistance testing after an accelerated polishing or wear treatment, because different types and patterns of wear are dictated by various environmental and usage conditions. One might expect high gloss tiles to become more slip resistant as the surface is scratched, while the slip resistance of some tiles will decrease as either the upper surface is worn away or fine matter collects in the troughs below the surface. Any coating, whether intentionally applied, or present as a consequence of vapour deposition or poor maintenance, will also influence the slip resistance. A marked decrease in the COF of some ceramic tiles has been observed where tiles have been used as secondary standards to determine whether the Pendulum is properly calibrated. It has not been conclusively determined whether this is due to wear of the tiles, deposition of rubber on the tile surface, or some other factor.

Where Pendulum results are used as the basis for selecting ceramic tiles, one might presume that this will mainly be for areas that the public have access to. These might be categorised as external areas (that must be expected to become wet), internal wet areas

[10]. Richardson, M.T., Rowland, F.J., Broughton, R.A. and Griffiths, R.S.: *'An Update on Research into Pedestrian Slipping'*, 1996, To be published.[14]. Koudine, A.A. and Barquins, M.: J. *Adhesion Sci. Technol.*, 1996, 10 (10), 951-961.

(that should be expected to become wet during use), transitional areas such as food courts (that should be expected to become wet on occasions) and dry areas (that might occasionally become wet due to routine maintenance or unforeseen spillages). In terms of the Pendulum results, the requirements in Table 4 might apply. One should note, however, that the use of some of the more slip resistant (class V and W) products may require the use of industrial cleaning machines. It may be desirable for less slip resistant products to be used in some circumstances, for instance, hotel bathrooms.

Category	Permitted classes
External areas	V, W
Internal wet areas	V, W
Transitional areas	V, W, X
Dry slopes	V, W, X, Y as determined to be appropriate
Dry level areas	V, W, X, Y, Z with FFT > 0.4

Table 4. *Possible slip resistance requirements for different pedestrian areas based on Pendulum test classification given in Table 1.*

Australian Standards are meant to represent minimum acceptable performance and not best practice. Provision of the proposed classification system allows those with a knowledge of a project to specify according to their perception of the appropriate level of risk. If AS/NZS 3661.1 becomes referenced in the Building Code of Australia, this will have the effect of making the Standard part of the guidance on how to comply with the provisions of the Code. The manner of incorporation would determine which of the Standard's requirements and recommendations form part of the Code and, therefore, would have evidentiary status. Regardless of how the Standard is referenced, the Committee is documenting a consensus agreement that is hopefully compatible with the specific needs of the Australian Building Codes Board. It is a technical document, written by people with technical expertise, to be interpreted in a technical, not a legalistic, manner.

It can be seen that adoption of Table 4 would neatly avoid any requirement for a classification for dry slip resistance. This is probably fortuitous since Dravitzki and Potter[11] found that most of the dry FFT COF results were clustered between 0.6 and 0.9. Furthermore, round robin studies by Bowman[12] and ATTAR [personal communication, 1997] have indicated that there can be a high variance associated with the results for some ceramic tiles. It should be noted that there is no external calibration procedure for the FFT.

Rubber can develop Schallamach waves and exhibit stick-slip behaviour on clean smooth flat surfaces such as float glass, due to interfacial adhesion[13], [14]. ASTM G 115, Standard Guide for Measuring and Reporting Friction Coefficients, states that when stick-slip behaviour occurs, the COF of the system is so variable that it is common practice to simply report 'stick-slip behaviour' for the test result rather than a numerical result.

Extreme caution should be exercised in interpreting individual FFT results because slight contamination, as will foreseeably occur in dry areas, would significantly alter some results. Another complicating factor with dry slip resistance measurements is that some are dependent on the prevailing relative humidity.

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[11]. Dravitzki, V.K. and Potter, S.M.: J. of *Testing and Evaluation*, 1997, 25 (1), 127-134.
[12]. Bowman, R.: in *Ceramics, Adding the Value*: AUSTCERAM 92, CSIRO Pubs, 1992, pp. 1071-6.
[13]. Grosch, K.A.: *Nature*, March 2 1963, Vol 197, No 4870, 858.
[14]. Koudine, A.A. and Barquins, M.: J. *Adhesion Sci. Technol.*, 1996, 10 (10), 951-961.

If an authority were to specify that floors in public shopping malls must have a dry FFT COF in excess of 0.6, this would exclude some ceramic tiles, terrazzos, stones and vinyls. The slip resistance of some of these excluded products in dry service conditions may be vastly superior to some of the products that might be permitted to be used. It is also highly probable that different test houses would obtain conflicting results. In such circumstances it would appear logical not to have a classification system for dry slip resistance as this could bring the entire Standard into disrepute, as well as unjustly penalising some manufacturers, merchants and consumers.

It would seem preferable not to have a classification system than to have one which might be misleading and cause contention. It should be recognised that accidents on dry floors are more likely to occur when dust is present as a contaminant. The FFT will often demonstrate the effect of dust and other contaminants most effectively: when the FFT is used on site, the COF will progressively decline as the slider becomes more contaminated. Since laboratory testing does not seek to determine the influence of dust (a contaminant that is unavoidable in most circumstances), the FFT result does not adequately discriminate and should not be expected to indicate the relative contribution of the dry floor surface to the risk of slipping when the Four S rubber is used. However, a different situation might apply if a less slip resistant 'shoe' material were used.

ASTM F 802, Standard Guide for Selection Election of Certain Walkway Surfaces When Considering Footwear Traction, contains useful information that is intended to assist in the selection of walkway surfaces where the presence of foreign materials may produce the danger of a slip or a fall. ASTM F 1637, Standard Practice for Safe Walking Surfaces, covers design and construction guidelines and minimum maintenance criteria for new and existing buildings and structures. While it is intended to provide reasonably safe walking surfaces for pedestrians wearing ordinary footwear, it may not be adequate for those with certain mobility impairments.

The German classification of commercial and industrial areas may be split into two broad categories: class R9 tiles are used on floors where the use of the area is such that there is not a high risk of slipping; and class R10 to R13 tiles are used in areas where there is an increased risk of slipping due to grease, oil, water, foods, left-overs, dust, flour, plant clippings, etc. Public toilets and washrooms require class R10 products. Although entrance areas to buildings only require class R9 products, the regulations require that the introduction of dirt and water is minimal due to appropriate preventative measures. While the German regulations stipulate that floors must be designed to prevent slipping, they must also be easy to clean. The proposed technical solutions do not exclude other acceptable safe solutions, and the classifications may be varied after due consideration of specific prevailing or anticipated conditions.

The French UPEC system for classifying floor coverings and rooms draws attention to slip resistance problems, but, pending development of a slip resistance test method, only assesses products on their resistance to wear, impact, water and chemicals. Nevertheless, it is interesting to note that the classification covers some 193 types of rooms. ISO 10545 results can be used to determine whether or not a particular type of tile is suitable for specific rooms, although a certain flexibility has also been introduced in the classification of some rooms to allow for varying levels of usage.

MEASUREMENTS ON SITE

One should consider that on-site slip resistance measurements will generally be made for one of two purposes: as part of a routine floor maintenance risk management program, or to investigate an accident. The results may thus be assessed in very different ways.

When a slip and fall accident has occurred, it is logical that one should seek to determine the slip resistance of the floor, and to compare it with both the slip resistance of the same product when new and any mandatory requirements. This presumes that the product has consistent slip resistance characteristics and that any published value is typical for the tiles that were installed. A number of product ranges have been found to exhibit very wide COF limits.

Post-incident slip resistance measurements may yield little useful information as to the cause of a specific accident. The coefficient of friction that is obtained with any test method is a function of the test method, the floor material, the 'shoe' material and the nature of any contamination. A different result would be obtained if one were to substitute a different shoe material, allow for the tread pattern and the relevant wear, adjust for the particular pedestrian gait, as well as simulating the contamination levels.

If we consider the case of 'calibration' tiles progressively yielding lower Pendulum values with continuing use in a controlled laboratory environment, one should not expect that products in service will yield comparable results to those obtained when they were first produced. This presumes that the tiles are not worn, and that their surface can be restored to an 'as manufactured' condition by an appropriate cleaning regime. However, there is no commonly accepted means of verifying that the tiles are satisfactorily clean. The situation becomes more complex if the slip resistance was not originally determined by the Pendulum method.

Where compensation is being sought for an accident, the victim's shoe may be unavailable to the 'defendant', and the soling materials may thus be unknown to the person whom they have engaged to assess the slip resistance of the floor. Although there may be several unknown factors, one can still obtain much data that may be useful in evaluating a slip and fall accident. ASTM F 1694, Standard Guide for Composing Walkway Surface Evaluation and Incident Report Forms for Slips, Stumbles, Trips and Falls is particularly useful in this regard.

Experts are often engaged several months after accidents have occurred and it is often the case that the floor is then being maintained in a different way. However, one should still try to ascertain the nature and timing of the last maintenance process before any measurements are made.

The FFT can be used to help determine whether the slip resistance of the floor is consistent, and if there are contaminants on the floor that are not immediately apparent. Measurements should be made in both highly trafficked and lightly trafficked areas, as well as in the vicinity of the incident. Measurements might also be made with one or more sole materials. Measurements can be made on the tiles in the condition that they are found, as well as after various cleaning procedures. Ancillary measurements such as surface roughness, slope, light conditions, weather conditions, surface conditions, and hardness of materials might also be made, together with a recording of the time, details of any warning signs or handrails, and a description of traffic paths, pedestrian density and lighting conditions.

Where a test device or configuration is used, other than the procedures nominated in the Standard, it is the responsibility of the individual using the equipment to confirm, using standard scientific and statistical methods, that the 'other' test equipment or methodology gives results consistent with those obtained by means of the Standard. There are many 'experts' using a variety of non-standard sled-based test devices, which can produce a range of conflicting results. Results only become meaningful when they are assessed against criteria that can be demonstrated to be relevant. One must have a fine appreciation of the inherent and potential deficiencies that are associated with any test procedure before one is in a sound position to use or interpret test results. Hopefully there will eventually be a general appreciation of any limitations of test methods that are adopted in Standards.

It is worth reflecting upon the fact that some resilient materials have a kinetic COF of 0.8 when tested with heavy steel sleds. This indicates excellent slip resistance. However, when tested with the Pendulum, the same products only obtain a lowly Y classification (according to Table 1). The stipulated test methods may not be appropriate to some on-site applications.

A FINAL ANALYSIS

Slip resistance is a complex multifactorial area. Individual slip resistance measurements, taken in isolation, can be misleading. A consideration of both slip resistance and surface roughness measurements will generally enable more appropriate product selections, but there are other factors that still need to be considered. However, highly detailed analyses are perhaps too academic to be generally useful. Product selection is not as simple a matter as specifiers would like it to be. While the German classification system provides useful guidance, particularly for specific industrial areas, one should always consider whether it might be appropriate, for a particular project, to specify in excess of the minimum requirements. The French UPEC system provides a far more detailed classification of rooms in private houses, administrative and commercial buildings, hotels, schools and hospitals. It will be interesting to see what slip resistance requirements are ultimately applied to these areas.

Specifying appropriate products is obviously an important step in preventing accidents. Monitoring the condition of floors in buildings can be based on slip resistance measurements. If one obtains an on-site pendulum result of 34 BPN (Four S rubber), does this indicate that some form of remedial treatment is required? The answer will always be dependent on the circumstances. One has to consider how the area is used, whether the footwear is subject to control, aspects of visibility, and a myriad of other factors. In all cases, it ultimately boils down to a matter of risk management. To take a parallel example, on roads, we may be able to accept a low COF on straight sections, but not at tight corners and busy intersections. If an car accident occurs at an intersection, we must consider more than the COF of the road when investigating its cause. Similarly, **there is no simple general solution to assessing the relevant contribution of a ceramic tile to a specific slip and fall accident.**

AS/NZS 4360, Risk management, provides a generic framework for identification, analysis, assessment, treating and monitoring of risk. While reference to it, in conjunction with AS/NZS 3661.2, should provide assistance in the design and maintenance of pedestrian surfaces, it may also be a useful tool in forensic investigations.

It has been suggested that there is more concern about slip resistance in Australia than elsewhere. If so, this may reflect the importance placed on providing safe, equitable and dignified access to a building and its services, as well as occupational health and safety matters. Standards are vital to improving public health and safety, and have a role in assessing and limiting any risk. However, suitably focused research is evidently still required.