Sustainable Slip Resistance: An Opportunity for Innovation

Carl J Strautins

Slip Check Pty Ltd, Sydney Australia
carl.strautins@gmail.com

Key Words: Slip Resistance, Accelerated Wear, Quality Management, Innovation

ABSTRACT

Ceramic tiles along with most flooring surfaces can become less slip resistant with use. This can occur rapidly such that some relatively new products can become hazardous within a short period of time. Currently there are no recognised methods to identify such problematic products. This introductory paper highlights the benefit of using accelerated wear test methods in combination with portable tribometers to evaluate long term slip resistance. These methods provide manufacturers an opportunity for innovation by identifying and satisfying consumers' expectations for sustainable slip resistant tiles. Product development occurs effectively through a systematic process of continual improvement. Manufacturers that develop suitable products will create a superior position in this growing niche market.

1 INTRODUCTION

Based on the current state of building construction and regulation, the main health and safety risks in buildings appear to be from slips trips and falls (Atech Group, 2003). While building regulations have reduced most societal risk, individual risks have been gaining prominence, particularly in developed countries where the cost of slip and fall public liability claims is high. European Union Directive 85/374/EEC, which applies to construction products, seeks to protect the physical well-being and property of the consumer. Defectiveness of the product is determined by reference not to its fitness for use, but to the lack of the safety which the public at large is entitled to expect.

Many building codes have safety performance requirements; not only for slip resistive surfaces, but also that they must continue to perform at the level they were originally required to achieve. This is emphasised by European Union Directive 89/106/EEC, such that tiles must be fit for their intended use over their working life to ensure the safety of occupants throughout the life cycle of a building. This is highlighted as a basic safety requirement of the Spanish Technical Building Code (Navarro 2006). "The objective of the basic requirement 'Safety in use' (SU) consists of reducing to acceptable limits the risk of users suffering immediate injury during the intended use of the buildings, as a result of their design, construction and maintenance characteristics" (Navarro et al 2006).

Safe design employs life cycle concepts and applies to every phase from conception through to disposal. As well as slip resistant flooring, risk minimisation strategies must take a holistic approach incorporating design features (awnings, airlocks and matting) to reduce the extent and likelihood of contamination, visual aids (warning signage and contrasting stair nosings), administrative controls (cleaning regimes and maintenance), fall prevention aids (barricades and handrails), environmental conditions (lighting and sloping surfaces) and specialised footwear.

Conscientious architects understand the need to specify floor surfaces in terms of slip resistance, obtain test results, and document that they have mitigated the risk of pedestrian slip incidents. Ideally the slip resistance of surfaces would not change; however, slip resistance audits have long confirmed that the performance of many seemingly slip resistant materials will reduce significantly over time. Thus test results obtained on factory fresh surfaces may be illusory, misleading designers into specifying products that may be potentially hazardous within weeks or months of installation.

This has serious implications for the architect when specifying a surface. The loss of slip resistance with use may be attributed to a range of complex interacting factors including the installation process, surface treatments, maintenance and wear. Slip resistance will always be part of a wider set of design objectives including practicality, aesthetics, cleanability, cost and functionality. These sometimes competing objectives need to be balanced in a manner that does not compromise the safety and health of those who access the building.

Currently there are no recognised accelerated wear test methods to assess or predict sustainable aspects of pedestrian slip resistance. Silva et al (2006) have proposed an enhanced method for assessing the durability of flooring exposed to pedestrian traffic, but the abraded area is too small for subsequent pendulum testing. Appropriate accelerated wear tests would enable organisations that design, construct and procure their own assets, to minimise their exposure to risk in slip and fall incidents and litigation.

One form of innovation is identifying what is incongruous between the reality 'that is' and the reality 'that should be' (Martin 2006). The reality is that slip resistance can deteriorate significantly over a short time; consumers assume that tiles will maintain sufficient slip resistance over time, if not the original amount. Highlighting the deficiencies in competitors' products (reality that is) whilst developing sustainable slip resistance tiles (reality that should be), provides a means for ceramic tile manufacturers to differentiate their products against their competitors, whilst satisfying the end users needs: thus providing an opportunity for innovation. This could be a winning competitive strategy in mature markets of developed countries such as the US. However, Bowman et al (ASTM STP 1424) question the accuracy of the American slip resistance test methods, highlighting the need for an ISO standard.

2 DEVELOPMENT OF AN ACCELERATED WEAR TEST METHOD

A Gardco 12VFI linear motion washability and wear tester was used to develop an accelerated wear test. This apparatus has traditionally been used to assess the wear resistance of paint systems using nylon bristle brushes. The machine has a 100mm x 100mm friction boat, which is cradled within a fork drive. Different abrasive materials were fixed to the bottom of the friction boat, which was set to operate at a rate of 50 cycles per minute, traversing backwards and forwards over a 300 mm path length. The pressure on the (water) wetted test specimen was controlled by adjusting the friction boat weight.

(a) Gardco linear motion washability and wear tester **(b) Pendulum slip resistance friction tester**

Figure 1. Initial investigation of test methodology using: (a) Gardco linear motion washability and wear tester; and (b) Pendulum slip resistance friction tester

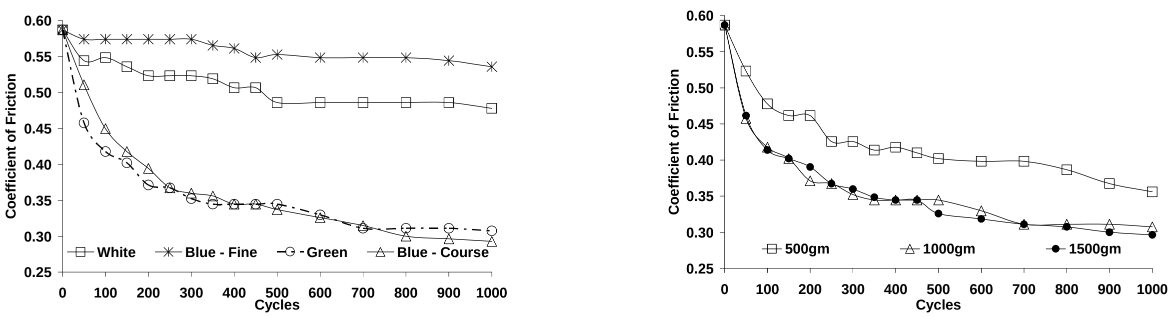
Initially the effect of the abrasive material and the applied pressure was investigated using a dust pressed, glazed ceramic tile. Four grades of 3M nylon cleaning pads were used for the study. They are identified by colour, in order of ascending abrasiveness: White - Light Duty No.98, Blue Fine -Power Pad No.2000, Green - Heavy Duty No.86, Dark Blue - Extra Heavy Duty No.88. These abrasive pads were used in combination with three weights of 500 g, 1000 g and 2000 g. A batch of 40 ceramic tiles were tested to AS/NZS 4586 using the wet pendulum with Four S (Slider 96) rubber material conditioned with P400 Grade abrasive paper, allowing tiles which measured a dynamic coefficient of friction (DCOF) of 0.59 to be selected for accelerated wear testing. The DCOF was re-measured after every 50 wear cycles to a total of 1000 cycles.

Further accelerated wear and wet pendulum testing was conducted, introducing a second ceramic tile. Both tiles had been used in the customer service area of several high traffic volume restaurants. From user opinion surveys, tile 1 was considered to maintain an acceptable level of slip resistance (it typically achieved a DCOF of 0.35 after 1 year when measured in situ), whilst tile 2 was thought to become hazardous after a short period of time, (DCOF of 0.20 after 1 year).

New specimens of these ceramic tiles were subjected to 100, 500, 1000 and 5000 cycles of accelerated wear using a Green 3M Scotch Brite abrasive pad with a total weight of 1000 g to determine the effect of pressure during abrasion.

2.1 Results

The results are shown graphically in Figure 2. Figure 2(a) depicts the relative difference between the 4 abrasive pads. While the white and fine blue abrasive pads resulted in slight ongoing changes in slip resistance, there was a more pronounced change with the coarse green and blue abrasive pads. The green pad was then used to evaluate the effect of applied pressure (500 g, 1000 g and 1500 g weights) as depicted in Figure 2 (b). No significant difference was observed between the 1000 g and 1500 g weights. The green pad was easier to mount to the friction boat than the coarser blue pad. The green 3M Scotch-Brite abrasive pad was thus selected with a 1000 g weight for accelerated wear use in an extensive range of further sustainable slip resistance studies.



(a) Comparison of 4 abrasive pads

(b) Comparison of 3 different weights

Figure 2. Initial investigation of test methodology using tile 1: (a) 4 different abrasive pads with 1000 g weight; and (b) Green Scotch Brite pad with 3 weights

The initial investigation of an accelerated wear test procedure indicated that a 3M green Scotch-Brite abrasive pad with weight of 1000gm, with rate of 50 cycles per minute over a 300mm path length was suitable for determining the loss in slip resistance using the pendulum friction tester. There was a noticeable smoother texture when the abraded tile was felt by hand, however the change was not detected using surface roughness parameter Rz. The greatest loss of slip resistance generally occurred during the first 50 cycles, with comparatively little loss after 500 cycles. The slip resistance after 500 cycles was found to be consistent with the in situ measurements at a high traffic volume restaurant after one year of usage. Thus a DCOF greater than 0.35 after 500 cycles appears to be a logical benchmark for new tiles that are likely to be used in similar high traffic usage scenarios.

3 EVALUATING THE LOSS OF SLIP RESISTANCE WITH INCLINING RAMP TEST METHODS

Having established that the probable slip resistance could be predicted by using the Gardco machine and the pendulum, the study was broadened to determine whether a similar accelerated wear treatment could be established for conditioning samples prior to using inclining ramp test methods. The oil wet ramp test is commonly used to classify the slip resistance of ceramic tiles however one limitation is that any subsequent loss of slip resistance cannot be measured without removal of the floor, as the test can only be conducted in the laboratory.

Ten different types of ceramic tiles were used for a series of comparative tests. A single Gardco treatment (5000 cycles) was chosen that was greater than approximately one years of wear within the setting observed. 500

cycles is equivalent to 85% of the loss in slip resistance that typically occurs after 5000 cycles using the pendulum test (unpublished results for over 30 ceramic tiles).

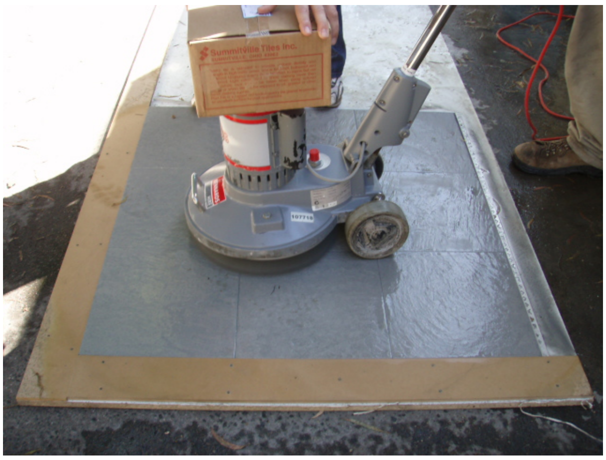
The Gardco accelerated wear test had been chosen for preparing specimens for pendulum testing since it could abrade an area that was sufficiently large to allow testing. Use of the Gardco machine was not practicable for preparing ramp test specimens given the 0.5m^{2}test area.

Table 1Generic description of ceramic tiles used to compare pendulum & inclining ramp test methods.

Tile	Description
A	Flat, dust pressed unglazed porcelain tile
B	Flat, dust pressed unglazed porcelain tile
C	Flat, dust pressed unglazed porcelain tile with carborundum chips
D	Flat, extruded unglazed quarry tile with carborundum chips
E	Flat, dust pressed porcelain tile with anti-slip glaze
F	Rock faced, dust pressed porcelain tile with anti-slip glaze
G	Profiled*, dust pressed unglazed porcelain tile
H	Profiled*, dust pressed unglazed porcelain tile
I	Profiled*, dust pressed unglazed porcelain tile
J	Profiled*, dust pressed unglazed porcelain tile

* A surface with a designed raised geometrical pattern that provides volumetric displacement.

Samples were first exposed to 5000 cycles of the accelerated Gardco wear procedure. The slip resistance was measured using the wet pendulum test method using both potable water and (the DIN 51 030 specified) oil. 0.5m^2 samples of each tile were then mounted separately on a board and subjected to wear using a floor polishing/buffing machine using a variety of abrasive cleaning pads. The position of the tiles on the board was changed during the procedure in an attempt to wear each of the tiles uniformly. The tiles were tested periodically using the pendulum friction tester (Slider 96) until the slip resistance had reduced equivalent to that of 5000 cycles of the accelerated wear procedure. Multiple measurements were conducted on each sample of worn tiles. Some minor variation may have occurred throughout the panels. One sample board was rejected as there was a difference in CoF between the Gardco accelerated wear samples and the polishing/buffing machine was greater than 0.02. The process was then repeated until the sample board conformed within ±0.02 CoF of the mean.



(a) Polishing/buffing machine used to wear tiles **(b) Inclining ramp testing apparatus**

Figure 3. Apparatus used for preparation and testing of samples for the inclining ramp test method.

3.1 Results

The experimental results are tabulated in Tables 2 and 3 below. Samples from the same batch that had not undergone treatment were used as control tiles, referred to herein as new or unworn tiles. The pendulum data for the worn tiles are those which had undergone the Gardco accelerated wear. The Pendulum testing procedure was conducted to AS/NZS 4586 with only one of each tile tested due to time and economic constraints. The Pendulum rubber test foot was conditioned using Grade P400 abrasive paper. The samples were tested after 0, 100, 500, 1000 and 5000 Gardco cycles without reconditioning of the test foot after each abrasive cycle.

Ramp testing was conducted at ATTAR test facilities located in Melbourne, Australia. The tangent of the ramp result angles (for one experienced walker only) were converted into coefficients of friction. The ramp tests with potable water (no wetting agent) were conducted with the walker wearing flat soled shoes that had been shod with Slider 96 rubber.

Table 2 Summary of experimental results with water contamination

Tile	Pendulum (slider 96) with Water		Inclining Ramp with Flat Soled Shoes & Water		Surface Roughness Rz (microns)	
	New	Worn	New	Worn	New	Worn
A	0.34	0.15	0.38	0.23	21.7	21.4
B	0.50	0.18	0.34	0.17	28.7	34.0
C	0.75	0.46	0.78	0.59	38.0	39.3
D	0.68	0.40	0.90	0.67	24.5	17.4
E	0.82	0.31	0.81	0.50	17.9	15.6
F	0.79	0.29	0.66	0.48	48.5	45.7
G	0.61	0.33	0.87	0.45	Nd	Nd
H	0.65	0.29	0.71	0.42	39.4	39.7
I	0.76	0.38	0.92	0.54	Nd	Nd
J	0.79	0.41	0.92	0.62	Nd	Nd

Note: The excessive volumetric displacement of tiles G, I and J did not allow surface roughness to be determined

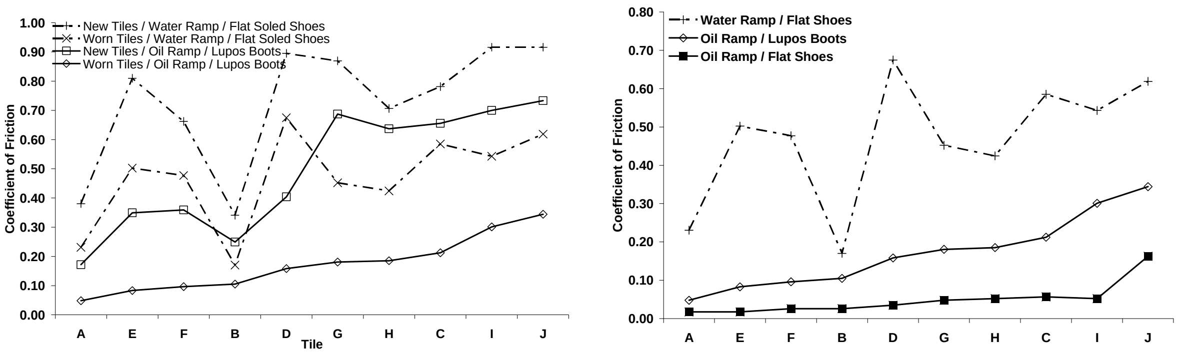
Table 3 Summary of experimental results with oil contamination

Tile	Pendulum (slider 96) with Oil		Inclining Ramp Test			
			Flat Soled Shoes		Standardised Boots	
	New	Worn	New	Worn	New	Worn
A	0.13	0.13	0.03	0.02	0.17	0.05
B	0.19	0.17	0.04	0.03	0.25	0.11
C	0.37	0.25	0.21	0.06	0.66	0.21
D	0.29	0.20	0.08	0.03	0.40	0.16
E	0.13	0.13	0.04	0.02	0.35	0.08
F	0.31	0.18	0.07	0.03	0.36	0.10
G	0.36	0.24	0.30	0.05	0.69	0.18
H	0.40	0.24	0.23	0.05	0.64	0.19
I	0.48	0.33	0.31	0.05	0.70	0.30
J	0.54	0.31	0.38	0.16	0.73	0.34

The samples that had undergone wear did not appear to change visually, with the exception of viewing under reflected light where a dull shine was observed for all worn specimens relative to unworn areas of the tile. This is probably as a result of a smoother micro-texture. The worn surface was detectably smoother when felt by hand even though the Rz surface roughness measurements did not detect a significant change in texture. Given the short path length of the surface roughness stylus, and the carborundum chip distribution in tiles C and D, it is unlikely that the chips were included in the measurements.

4 Discussion

Figure 4(a) shows the results graphically of the coefficient of friction for both new and worn tiles using inclining ramp with water and flat soled shoes shod with slider 96 rubber prepared with P400grade paper. The standardised safety boots were not prepared with abrasive paper when ramp testing with oil as a contaminant. The results were ranked in an ascending order of worn tiles when tested to DIN 51 030. After the equivalent of 5000 cycles of wear the reduction in slip resistance was noteworthy. There was a reduction of between 25-50% when measured with the water ramp test and 53-75% with the oil wet ramp test.



(a) Comparison of new and worn tiles (b) Comparison of shoes and fluid for worn tiles

Figure 4. Investigation of inclining ramp test methodology (a) difference between new and worn tiles using water and oil for the ramp test; and (b) comparison of shoes used and contamination.

Figure 4(b) shows the comparative difference in coefficient of friction between the three inclining ramp tests conducted after the equivalent wear of 5000 cycles. The relative difference between the results is due to the type of intermediate fluid, footwear soling material and tread pattern, since the friction mechanisms vary significantly in these situations. Different tribometers, operating on different principles, often give different results as an inherent function of the tribometer and, thus, may underestimate or overestimate the available traction in some circumstances.

It is important to understand that tribometers measure the friction of the two interacting surfaces and any solid or liquid medium within the system. It seems sensible that test methods should be used to simulate the intended conditions for normal usage in terms of the contaminant likely to be present and the footwear intended to be worn. For example, the inclining ramp test using water and flat soled shoes is more appropriate for most external walkways and entry foyers, where the most likely contaminant is water and many people will be wearing shoes that may have a hard soling compound and a worn tread pattern.

The oil wet ramp test, which uses safety boots with large volumetric tread pattern and high viscosity motor oil, seems to be of little relevance for normal conditions (that the general public will normally encounter). The oil wet ramp test is more suitable for commercial kitchens and industrial areas, where people will be using specialised shoes and viscous contaminants are likely to be encountered. The interlocking of the safety shoe tread with a highly profiled floor surface can provide a means of achieving traction that is not available to many types of footwear. The oil wet ramp result will thus overestimate the traction that will be available to normal footwear on most surfaces as shown in Figure 4b. Although the ranking order of these tiles was the same for both types of footwear for the oil wet conditions, it is worth noting that the standardised boots provided better differentiation (in that there was a greater spread of results).

The new Spanish Technical Building Code establishes slip resistance requirements for floors in buildings and public circulation areas. Unworn specimens must be tested according to UNE-ENV 12633:2003 and are classified according to the pendulum value Rd. Table 1.2 of the Basic Document SU-1 specifies the slip resistance compliance criteria for different areas of use, such as health, educational and commercial. This standard uses CEN rubber as the pendulum slider material rather than Slider 96. CEN slider material is more resilient (feels softer) than Slider 96, and gives very different results (Bowman et al 2005).

There is no correlation between the slip resistance results achieved with these two slider materials due to their different compositions and material characteristics. However Slider 96 appears to be a more logical choice as it is more closely related to the soling material of common dress/business footwear that would be used in commercial settings. Given the soft yielding nature of the sole of the human foot after prolonged water immersion, resilient rubber test feet are likely to provide the best surrogate for assessing wet barefoot slip resistance. Thus the CEN slider material may be more suited to swimming pool surrounds and the like. The original TRRL rubber (which is similar to CEN rubber) has been used for this purpose.

Table 1.2 of the Basic SU Document require that internal dry surfaces in public areas achieve a minimum of Class 1 ($Rd > 15$). This safety requirement does not consider sensible design measures such as awnings, airlocks and matting to limit contamination and may discriminate against the use of polished and smooth glazed tiles within internal dry areas. However if appropriate control measures ensure that the area remains dry and clean when in use, tiles that that do not obtain Class 1 may still prove suitable for the intended use.

UNE-ENV 12633:2003 may not be an appropriate test for commercial kitchens and industrial areas, where people will be using specialised shoes and viscous contaminants. Water as the intermediate fluid and use of the CEN slider is unlikely to replicate the available friction for the range of anticipated conditions when in use. The pendulum with Slider 96 and oil in conjunction with the accelerated wear test procedure appears to be a more suitable method to assess the long term slip resistance. A CoF of 0.35 after 500 cycles for heavily trafficked industrial areas provides a logical initial benchmark when testing with oil. However this needs to be assessed in the light of user surveys. Tiles I & J achieved a CoF of 0.40 and 0.36 respectively.

Although not detected using Rz as a surface roughness parameter, it is postulated that the inherent slip resistance is affected primarily due to the micro-texture of the ceramic tile surface being polished as the asperities are worn down. For profiled tiles, the upper surface will preferentially wear as this is where foot contact predominantly occurs. Thus the wear resistant characteristics of the tile are most important. The wear of the tile surface is even more critical where there is no significant interlocking effect between the shoe tread and the surface profile. Mechanically aggressive cleaning systems are known to have caused near-instantaneous slip resistant losses in some surfaces. Thus the cleaning and maintenance regime should be considered when assessing the potential long term slip resistance of a flooring system.

A sensible approach in selecting a test method that provides a realistic indication of slip resistance should be based on the anticipated environmental conditions and the likely wear. The Australian slip resistance test methods given in Table 4 enable the selection of tiles but only the pendulum confirms the onsite performance. Using the appropriate slip resistance tests after exposing specimens to accelerated wear should provide the most pragmatic assessment of pedestrian safety.

Table 4 Australian suite of slip resistance tests to be used in particular environmental conditions.

Test Method	Contamination	Footwear	Example
Pendulum	Water	Simulation of Smooth Soled Shoes	External surfaces and internal foyers
Inclining Ramp	Water	Bare Feet	Swimming pool surrounds
Inclining Ramp	Oil	Profiled Safety Boots	Commercial kitchens & industrial workshops

Comparing both new and worn surfaces in water conditions, the pendulum generally underestimates the ramp results. If one assumes that the ramp test provides the best indication of the slip potential of products, one might conclude that any assessment of the likelihood of slipping should be based on derived ramp results. As studies have shown that there is a reasonable correlation between these conditions, a correction factor should be integrated within a quantitative risk assessment when utilising the pendulum. Assuming that the worn tile provides a truer indication and removes the sensitivity that either the ramp or pendulum may have, the following relationship was obtained for the diverse range of worn tiles tested;

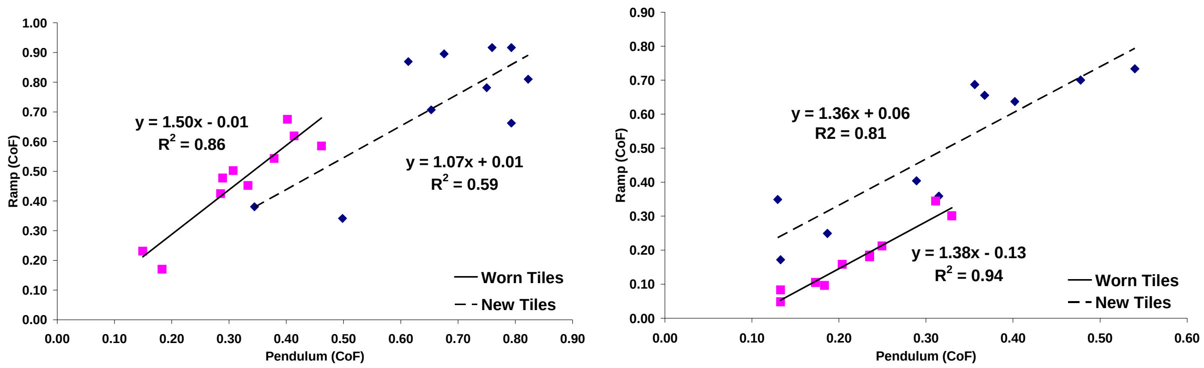
$$\mu_{\text{Ramp water}} = 1.46\, \mu_{\text{Pendulum water}} \qquad (R^2 = 0.87)$$

Better agreement might be obtained for families of tiles which have similar surface characteristics. Any correction factor should be based on the relevant tile family, not a generalized one. Silva (2006) has shown that there is poor correlation between the oil wet ramp test and the water wet pendulum test using CEN rubber. This concurs with the results of this study using slider 96. Based on the ten ceramic tiles, a reasonable relationship was exhibited between the oil wet ramp test and the pendulum using oil;

$$\mu_{\text{Ramp oil}} = 1.32\, \mu_{\text{Pendulum oil}} - 0.12 \qquad (R^2 = 0.94)$$

These results and relationships should be seen as indicative due to the small sample size and the use of one walker; however this data provides a useful bench mark until further data is collected. In the case of both relationships, there was greater correlation between results for the worn tiles than the new factory fresh tiles.

The Ceramic Tile Institute of America, Inc [8] endorses improved portable test methods as long as they demonstrate that correlation coefficient R^2 is 0.81 or higher. The sample size must be greater than 14 with samples well-distributed over the ramp test categories R9 through R 13. The significance of this initial study is that worn tiles tested insitu with the pendulum can provide a reasonable indication of the available friction.



(a) Comparison of water contamination (b) Comparison of oil contamination

Figure 5. Plot of inclining ramp versus pendulum on both new and worn tiles using different lubricating mediums (a) water; and (b) oil.

4.1 Integration of slip resistance within a Quality Management Framework

Successful innovation, such as sustainable slip resistant tiles, arises from an outward approach: towards the market, towards the consumer. Organisations that design, construct and procure their own assets recognise that sustainable slip resistant surfaces help to mitigate their risk of slip and fall incidents, as well as possible litigation. Effective innovation occurs by means of a systematic process, not from flashes of genius. Accelerated wear test methods and ongoing auditing will give manufactures the necessary feedback required to benchmark their tiles. Quality Management Systems implement a methodology known as "Plan-Do-Check-Act". This can then be applied to develop sustainably slip resistant ceramic tiles:

Plan: Review current consumer's needs and values and identify potential new markets. This will be of benefit to organisations that design, construct and procure their own assets.

Do: Audit current products and their slip resistance performance with wear and examine the adequacy of current manufacturing processes. Implement accelerated wear test procedure and establish benchmarks. Preliminary data indicates that a DCOF greater than 0.35, using the pendulum after 500 accelerated wear cycles, appears to be a suitable benchmark when using Slider 96 rubber;

Check: Periodically monitor the in situ performance of tiles that have been laid to correlate results with the accelerated wear test procedure and assess product development. This can also be used to predict the probable long term slip resistance of surfaces (assuming they are properly maintained); and

Act: Review the development process and take action, if necessary, to modify the initial accelerated wear benchmarks to continually improve the development of sustainably slip resistant ceramic tiles.

Onsite testing with a reliable tribometer is an essential element within a continual improvement cycle to correlate accelerated wear procedures with insitu results. Appropriate slip resistance compliance criteria must also be based on: utilised friction demands, incidents and user opinions on existing floors, along with insitu testing with anticipated contaminants. This will enable accelerated wear criteria to be established which seek to predict the probable long term slip resistance and increase the safety of occupants over the lifecycle of a building. The results must then be evaluated to review and potentially modify the initial compliance criteria.

The pendulum is capable of being used with a variety of liquid and dry contaminants, as well as pastes, margarine, etc. The pendulum can be used with different test feet, and it is well suited for conducting trials in industrial installations such as commercial kitchens, using oil or other contaminants. The inclining ramp test methods are poorly suited for quality management system usage, as tests cannot be conducted onsite. Despite this, ramp tests can be useful for assessing the footwear that might be worn on such floors. Even though buffing machines lack the control desired in accelerated conditioning treatments, some ramp testing of abraded specimens is better than none. Given the anecdotal evidence that some worn profiled surfaces pose a significant slip risk, and the effectiveness of heavily cleated footwear will decrease with wear and the pick-up of solid contaminants, multiple measurement techniques will always provide the optimum outcome.

5 Summary

This initial investigation highlights the potential benefit of accelerated wear test methods in order to determine the probable long term slip resistance of tiles. It also provides a logical starting point in a process of continual product development. Comparisons of slip resistance test results emphasise the selection of appropriate test methods to ensure specification of suitable products for the anticipated conditions. This study indicates that the pendulum is a suitable tribometer, and that it is an essential element within a continual improvement cycle to correlate accelerated wear procedures with insitu results. Manufacturers have an opportunity for innovation by identifying and satisfying consumer expectations for sustainable slip resistant tiles, where this expectation can be effectively realised through a systematic process of continual improvement.

The beneficial impact of such accelerated wear techniques is evidenced by a number of prominent multinational companies who have implemented internal standards based on this test methodology. These organisations design, construct and manage their own assets, and needed to minimise their exposure to risk in slip and fall incidents and litigation. The same methodology enables ceramic tile manufacturers to differentiate their products against their competitors, whilst satisfying the end users needs: thus providing an opportunity for innovation.

Acknowledgements

The author would like to acknowledge Patrick Leong, Richard Earp and Richard Bowman for their continued support over the years

References

[1] Atech Group Health and Safety Risks in Buildings, Executive Summary, Main Findings and Recommendation, Technical report to Australian Building Codes Board 2003

[2] Bowman, R, Strautins, CJ, Westgate, P, and Quick, GW, Implications for the development of slip-resistance standards arising from rank comparisons of friction-test results obtained using different walkway-safety tribometers under various conditions, *Metrology of Pedestrian Locomotion and Slip Resistance*, STP 1424, 2002, M. Marpet and M.A. Sapienza, Eds., American Society for Testing and Materials, West Conshohocken, PA, pp 112-136.

[3] Bowman R, Quick G W, Strautins C J, and McEwan T, 2003, 'Initial findings extracted from the CSIRO wet slip resistance database' Proceedings of International Ergonomics Association XVth Triennial Congress, 24-29 August 2003, Seoul, Korea, Vol. 6, 4 pp.

[4] Bowman R, Strautins C J, & My Dieu Do, 'Beware of conflicting stone slip resistance reports' *Discovering Stone*, March 2005, p. 26.

[5] Martin, J. S. The Opportunity for Innovation, Qualicer 2006, IX World congress on ceramic tile quality, Castellon Spain, Vol. 1, pp P.BA 93-106.

[6] Navarro, J. P, Francisco G. O. Olmos. Ceramic Tiling Before The New Requirements Of The Technical Building Code, Qualicer 2006, Vol. 1, pp P.BB 43-60.

[7] Silva, G, Muñoz, A, Feliu, C, Monzo, M, Barbera, J, Soler, C. Proposal of a standard method for determining the durability of flooring exposed to pedestrian traffic. Qualicer 2006, Vol. 3, pp P.BC 217-236.

[8] Silva, G, Muñoz, A, Monterde, B, Quereda, F, Comparative analysis of slip resistance requirements in trafficked public premises, Qualicer 2006, IX World congress on ceramic tile quality, Castellon Spain, Vol. 3, pp Pos 35-38.

[9] http://www.ctioa.org/reports/cof16.html "Endorsement of Improved Test Methods and Slip Prevention Standards for New Flooring"