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Sustainable Slip Resistance: An Opportunity for Innovation

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ABSTRACT

Ceramic tiles along with most flooring surfaces will reduce in slip resistance with use. This can occur rapidly such that relatively new surfaces can become hazardous over a short period of time. Currently there are no recognised methods to assess these 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 consumer's expectations for sustainable slip resistant tiles. Product development occurs effectively through a systematic process of continual improvement. Manufactures 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.

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 which applies to construction products, such that they must be fit for their intended use over their working life to ensure the safety of occupants throughout the life cycle of a building.

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 nosing's), 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 incident. Ideally the slip resistance of surfaces will not change; however, slip resistance audits have confirmed that the performance of many seemingly slip resistant materials will reduce significantly over time. When Australian Standards Committee BD-094, *Slip Resistance of Flooring Surfaces*, set the recommendations of slip resistance in specific locations, it was anticipated that the slip resistance will reduce in most circumstances. The degree had not been quantified, yet it was wrongly assumed that it would not be fundamentally significant.

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. Such 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.

Peter Drucker proposes that one form of innovation is identifying what is incongruous between the reality ‘that is’ and the reality ‘that should be’. The reality is that slip resistance can deteriorate significantly over a short time; the assumption of the consumer is that the slip resistance will maintain its original level over time. Highlighting the deficiencies in competitor’s products (reality that is) whilst developing sustainable slip resistance tiles (reality that should be), provides ceramic tiling manufacturers a method 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.

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 test specimen was controlled by adjusting the friction boat weight and water is used to assist in abrasion.

(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

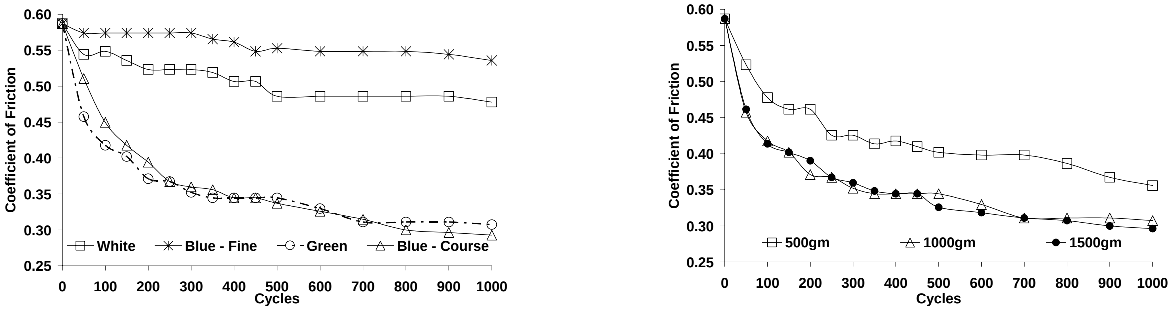
Initially the effect of the abrasive material and the applied pressure was investigated using a dust pressed, glazed ceramic tile. Four grades of 3M nylon cleaning pads were used for the study. They are identified by colour, in order of ascending abrasiveness: White - Light Duty No.98, Blue Fine -Power 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, 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 high traffic volume restaurants. From user opinion surveys, tile 1 was known to maintain an acceptable level of slip resistance (typically achieving a DCOF of 0.35 after 1 year when measured in situ), whilst tile 2 had been found to become hazardous after a short period of time, (DCOF of 0.20 after 1 year).

The ceramic tiles were also 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 1 (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. Hence the reason why the 3M green Scotch-Brite abrasive pad with a 1000 g weight was selected 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 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.

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

A futher investigation of 10 ceramic tiles was conducted to compare the comparative loss of slip resistance between the pendulum and inclining ramp test methods after an accelerated wear procedure. The oil wet ramp test is commonly used to classify the slip resistance of ceramic tiles however one limitation is that any subsequent losses of slip resistance cannot be measured insitu. Thus the purpose was to attempt to observe if there was correlation between the test methods. A cut off point of 5000 cycles was chosen where the level of slip resistance had appeared to asymptote.

The initial accelerated wear test was chosen due to the relatively compact size to conduct testing on samples to be evaluated with the pendulum friction tester. Construction of an accelerated wear machine was not practicable due to the size required to perform uniform wear cycles over an area of $0.5m^2$.

Table 1Generic description of the tiles used to compare pendulum and inclining ramp test methods.

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

Samples were first exposed to 5000 cycles with the accelerated wear procedure and the friction was measured using the wet pendulum test method using both potable water and oil (as specified in DIN 51 030). 0.5m^2 of samples were then constructed on a board and then 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 rotated throughout the procedure in an attempt to wear the tiles uniformly. The tiles were tested periodically using the pendulum friction tester (Slider 96) until the slip resistance has reduced equivalent to 5000 cycles on the accelerated wear procedure.

(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.

Table 2 Summary of experimental results with water contamination

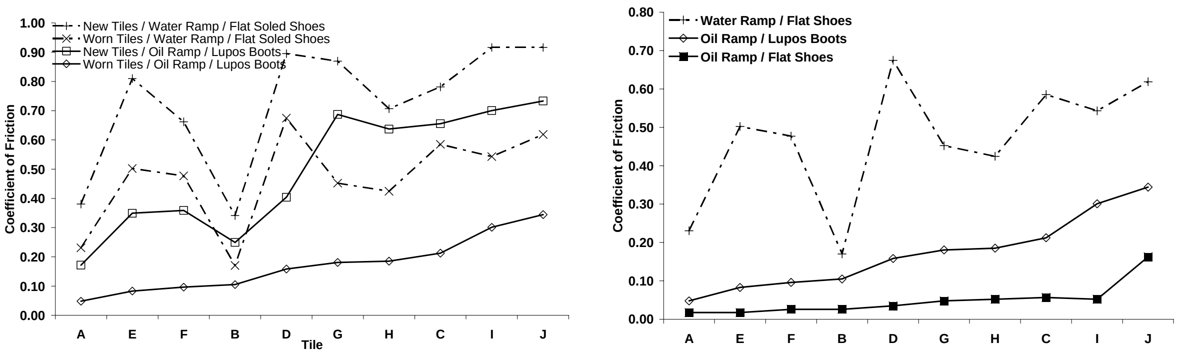
Tile	Pendulum (slider 96) with Water		Inclining Ramp with Flat Soled Shoes & Water		Surface Roughness Rz (microns)	
	New	Worn	New	Worn	New	Worn
A	0.34	0.15	0.38	0.23	21.7	21.4
B	0.50	0.18	0.34	0.17	28.7	34.0
C	0.75	0.46	0.78	0.59	38.0	39.3
D	0.68	0.40	0.90	0.67	24.5	17.4
E	0.82	0.31	0.81	0.50	17.9	15.6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

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

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 material and oil as a contaminant with the standardised safety boots. The results were ranked in an ascending order of worn tiles tested to DIN 51 030.After the equivalent of 5000 cycles of wear the reduction in slip resistance was significant. There was reduction between 25-50% when measured with the water ramp test and between 53-75% with the oil wet ramp test.



(a) Comparison of new and worn tiles

(b) Comparison of shoes and contamination

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

Figure 4(a) shows the comparative difference in coefficient of friction between the 3 inclining ramp tests conducted after the equivalent wear of 5000. The relative difference between the results for the three conditions 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 with 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. 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.

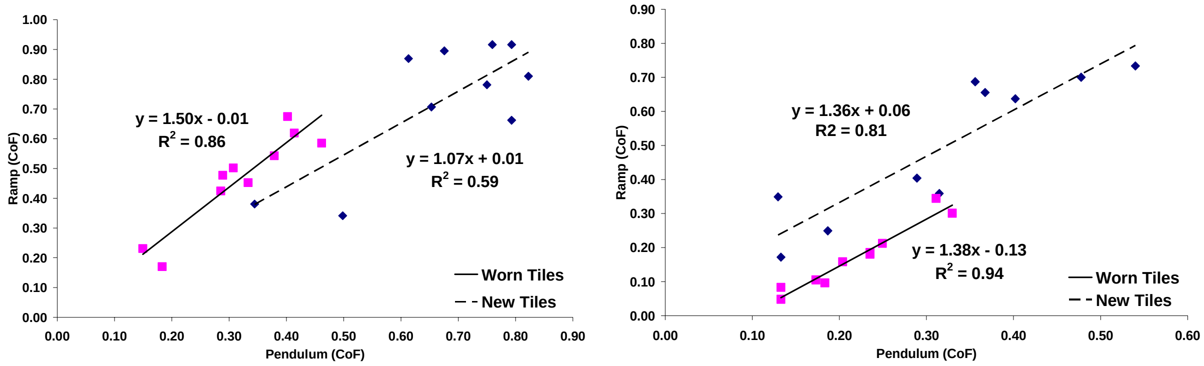
Although not detected using the surface roughness meter, it is postulated that the inherent slip resistance is affected primarily due to the micro-texture of the ceramic tile surface being polished as the asperities are worn down. Mechanically aggressive cleaning systems are known to have caused near-instantaneous slip resistant losses in some surfaces. Thus the cleaning and maintenance regime must be taken into consideration when assessing the potential long term slip resistance of a flooring system.

A sensible approach in selecting the appropriate test method should be based on the environmental conditions, including wear, which they would anticipate for the building usage. This is best illustrated with suite of Australian slip resistance test methods as shown in Table 4. This provides a realistic value of friction in order to assess pedestrian safety.

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

AS/NZS 4586	Tribometer	Contamination	Footwear	Example
Appendix A	Pendulum	Water	Smooth soled shoes	External surfaces and internal foyers
Appendix B	Tort	Dry powder	Smooth soled shoes	Internal dry areas such as shopping centres
Appendix C	Inclining Ramp	Water	Bare Feet	Swimming pool surrounds
Appendix D	Inclining Ramp	Oil	Profiled Safety Boots	Commercial Kitchens & workshops

Whilst is has previously been shown that there is no correlation between the oil wet ramp test and the water wet pendulum test there was a strong correlation found between the oil wet ramp test and the pendulum using oil as the lubricant. Studies have also shown that there a relatively good correlation between the inclining ramp with water lubricating the surface and the wet pendulum test. In both cases there was greater correlation between with the worn tiles than new factory fresh tiles and the respective test method.



(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.

Based on the 10 ceramic tiles, a reasonable relationship (R^2 = 0.81) was exhibited between the oil wet ramp test and the pendulum using oil; the correlation was greater for worn tiles (R^2 = 0.94). The significance of this is that worn tiles insitu tested with the pendulum can provide a reasonable prediction of the oil wet ramp test result.

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 the value of sustainable slip resistant surfaces assist 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 provide manufactures the necessary feedback required to benchmark their products. 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;

Check: Periodically monitor the in situ performance 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 and provides a logical starting point in a continual process of 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. It indicates that the pendulum is a suitable tribometer that is an essential element within a continual improvement cycle to correlate accelerated wear procedures with insitu results This provides manufacturers an opportunity for innovation by identifying and satisfying consumer's expectations for sustainable slip resistant tiles and occurs effectively through a systematic process of continual improvement.

The impact of accelerated wear techniques are highlighted by multinational companies who have implemented internal standards based on this test methodology. This enables organisations that design, construct and manage their own assets, to minimise their exposure to risk in slip and fall incidents and litigation. Additionally this provides ceramic tiling manufacturers a method to differentiate their products against their competitors whilst satisfying the end users needs: thus providing an opportunity for innovation.

SUMMARY

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

[2] Julian Perez Navarro, Francisco Garcia Olmos. Ceramic Tiling Before The New Requirements Of The Technical Building Code, Qualicer 2006, VIII World congress on ceramic tile quality, Castellon Spain, Vol. 1, pp P.BB 43-60.

[3] Javier Sastre Martin The Opportunity for Innovation, Qualicer 2006, VIII World congress on ceramic tile quality, Castellon Spain, Vol. 1, pp P.BA 93-106.

[4] 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, M. Marpet and M.A. Sapienza, Eds., American Society for Testing and Materials, West Conshohocken, PA, pp 112-136.

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