BEWARE OF CONFLICTING STONE SLIP RESISTANCE REPORTS

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This article was initiated by an enquiry: "Is a honed marble with a minimum pendulum value of 43 BPN suitable for use in the foyer of a public building?" Such a simple enquiry raises several issues. Conflict resolution normally implies that there are two or more parties to an issue. However, any inherent conflict may not be apparent when one receives technical product literature or the test data it is based on. There is a need to be very wary of slip resistance reports that have not been prepared in accordance with the Australian Standards.

Australians would tend to associate a result of 43 BPN with class X according to AS/NZS 4586:2004, *Slip resistance classification of new pedestrian surface materials*. However, this presumes that a Four S rubber has been used after it has been prepared on grade P 400 abrasive paper. Such presumptions are very dangerous. In this instance, the honed marble had been tested according to NF EN 1341:2003, *Slabs of natural stone for external paving – Requirements and test methods*. This French standard is equivalent to the British version of the same European standard, BS EN 1341:2001.

The complexity raised by standards using similar pendulum test procedures was central to our paper,[1] "Practical aspects of slip resistance of stone". This introduced the Australian slip resistance standards and reported that:

> "In the European external paving stone standards, EN 1341 and EN 1342, a TRRL rubber is used in the pendulum to measure the wet slip resistance of at least six saturated stone specimens. The rubber is conditioned using a surface that has a BPN value of over 40 when dry (permitting a wide range of sandpapers). The producer is required to declare a minimum unpolished slip resistance value (USRV) expected for individual specimens of fine textured stone. All test specimens must have a result not less than the declared value. The USRV relates to stone as manufactured and helps to ensure adequate slip resistance on installation."

BS EN 1341:2000 requires a minimum of six specimens. BS EN 1341:2001 requires a minimum of five specimens. BS EN 14231: 2003, *Natural stone test methods – Determination of slip resistance by means of the pendulum tester,* requires a minimum of six specimens. EN 14231 is used for measuring the slip resistance value of the surface of the exposed face of natural stone elements intended to be used for flooring in buildings. The EN 14231 test procedure is otherwise virtually identical to that of EN 1341, except that EN 14231 requires that results be corrected for temperature to allow for changes in the resilience of the rubber. The method may be used for laboratory measurements or on floors in service. If the surface of the exposed face has a roughness greater than 1 mm it will be considered as not slippery without performing the test. This height difference lies between the EN 1341 definitions of fine textured (0.5 mm maximum difference between peaks and depressions) and coarse textured (more than 2 mm difference) stones. EN 14231 does not suggest what reading might indicate that a fine textured stone is safe or non-slippery, but EN 1341 indicates that unpolished slip resistance values of greater than 35 can usually be considered safe. The British Stone list considers that values greater than 40 are safe, http://www.projects.bre.co.uk/ConDiv/stonelist/index.html.

The European natural stone technical committee (CEN/TC 246) considered that coarse textured stones could not be reliably tested, although others would disagree. EN 1341 assumes that coarse textured stones have satisfactory slip resistance for external paving.

For a product to obtain a classification of V, AS 4586 requires a minimum mean of 45 BPN with the TRRL rubber (with 36 as the minimum possible individual value). We stated:

> "Given the similarity of the test methods, and that the manufacturer is declaring a minimum value (which implies testing of far more than five specimens), merchants may be able to place some trust in results that have been obtained in accordance with EN 1341 and 1342. A declared USRV of 36 might be equivalent to class W".

In order to assess the potential effects of the pendulum test variants introduced by EN 1341 and BS 7976, the preliminary research that was reported indicated the critical importance of the conditioning of the rubber slider, and the need to use lapping film when preparing sliders for testing very smooth surfaces.

It was noted that:

> "when a 60-grade paper is used to condition the TRRL slider (as in ASTM E303) the pendulum results are higher on polished tile surfaces than when the slider is conditioned on 400-grade paper. EN 1341 fails to define a specific material for conditioning the TRRL rubber. This does not present a problem if the rubber is conditioned on the typical surface finish that is to be tested. However, this rubber should then be restricted to use on that surface finish. Further rubbers should be conditioned for exclusive use on other surface finishes".

This paper presents further results and proposes possible amendments to the EN standards for determining the slip resistance of stone to enable more consistent reporting.

Rubbery differences

The most significant difference between AS 4586 and EN 1341 lies in the choice of rubber and the method of its preparation. AS 4586 states: "The standard slider shall be either Four S rubber (simulated standard shoe sole) (IRHD hardness 96 ± 2) or TRL (Transport Research Laboratory) rubber (IRHD hardness 55 ± 5)". EN 1341 requires that the initial IRHD hardness of the slider shall be within the range of 53 to 65, and that the initial resilience comply with the table below.

Temperature (°C)	0	10	20	30	40
Resilience (%)	43 to 49	58 to 65	66 to 73	71 to 77	74 to 79

The above table is consistent with the specification limits for both the TRL (also known as TRRL) and CEN rubbers. Since CEN rubber has a specified limit of 59 ± 6 IRHD, all certified batches of CEN rubber can be used for testing to EN 1341. TRL rubber has a specified limit of 55 ± 5 IRHD. While some batches of TRL rubber are suitable for testing to EN 1341, many recent batches of TRL rubber have had a hardness of 51 or 52, and thus should not be used for testing to EN 1431.

Returning to the enquiry, the test report does not state which rubber was used. EN 1341 does not require the report to state which rubber was used.

AS 4586 requires that the rubber slider shall be conditioned using grade P 400 abrasive paper, before testing each sample (a minimum of five individual specimens).

"The readings on the scale shall be within ± 2 of a consistent number lying within the range of 85 ± 10 for the Four S rubber or 115 ± 10 for the TRL rubber during the conditioning of the slider".

This imparts a consistent level of roughness to the rubber. New sliders are given a chamfered edge by passing the slider 10 times across the abrasive paper.

EN 1341 requires that: "Before using a new slider it shall be conditioned to produce a minimum width of striking edge of 1 mm". "This shall be achieved by setting up the tester and carrying out 5 swings on a dry surface with a friction value above 40 . . . followed by a further 20 swings on the same surface after wetting". There is no requirement to subsequently condition the slider, e.g. to give the rubber a similar degree of surface roughness before testing each sample.

BS 7976-2:2002, *Pendulum testers – Method of operation*, requires that new rubber sliders shall be prepared by carrying out 10 swings across a sheet of 400-grade silicon carbide resin bonded paper in either wet or dry conditions. Where a Four S rubber slider is to be used for testing smooth surfaces (i.e. those with a roughness of less than 15 μm Rz) a further 20 swings shall be carried out across a sheet of 3M 261X ImperialTM Lapping Film Grade 3MIC or an equivalent product in wet conditions. The purpose of this 'polishing' of the rubber is to ensure that the test result reflects the slip resistance of the product rather than reaching a limit that is determined by the roughness of the rubber. This enables better differentiation of the relative slip resistance of the products that have least wet slip resistance.

The product being tested will inevitably cause some wear of the slider. The amount and rate of wear is a function of the hardness, sharpness and size of the textured relief of the product. **Figure 1**

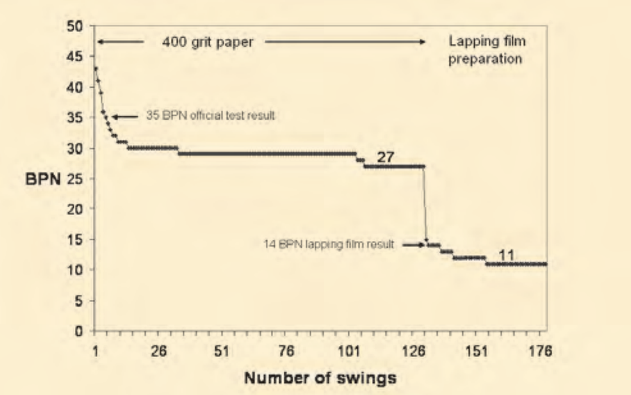

Figure 1 Effect of lapping film preparation of Four S rubber on the results for a honed marble with a surface roughness of 3.6 μm Rz.

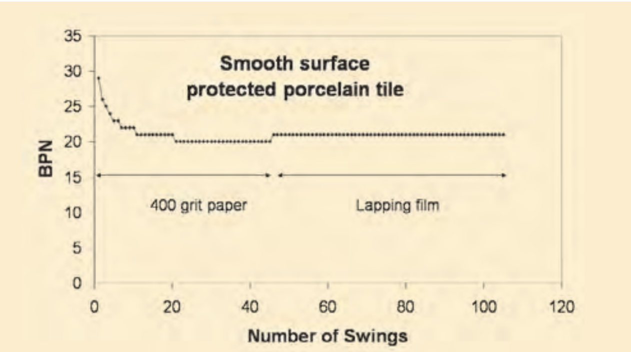

Figure 2 Effect of lapping film preparation of Four S rubber on the results for a smooth surface protected porcelain tile with a surface roughness of 11.5 μm Rz.

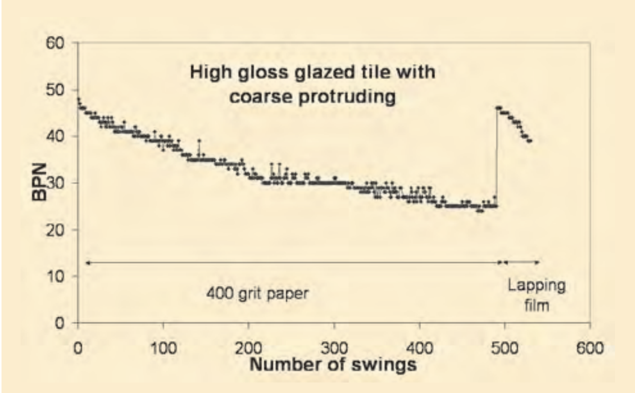

Figure 3 Effect of resurfacing a Four S rubber with lapping film when testing a high gloss glazed tile with coarse 100 mesh alumina particles penetrating above the surface. The tile had a mean surface roughness of 9.6 μm Rz.

shows a progressive decline in results as the Four S slider was slowly polished by a honed marble. However, there was a dramatic decrease in the result when the lapping film was used to polish the rubber.

Figure 2 gives an example of a product where lapping film preparation had minimal effect. While the smooth surface protected tile has a result of 24 BPN and just fails to qualify for class Y, it is intrinsically more slip resistant than the class X honed marble in **Figure 1.**

Figure 3 gives an unusual example of where lapping film preparation caused an increase in the test results. In this instance, continued testing of the tile surface caused the Four S slider to become severely scored by the protruding alumina particles, progressively minimising the degree of interaction between the slider and the tile. Resurfacing the rubber with any medium grade of abrasive paper would have had a similar restorative effect.

Granite finish	Rz μm	Grade 60 paper TRL	Grade 60 paper CEN	P 400 paper TRL	P 400 paper CEN	Lapping film TRL	Lapping film CEN
120 grit	11.5	42	41	34	36	27	28
180 grit	11.4	42	41	35	33	25	26
320 grit	10.7	39	41	29	35	16	17
400 grit	9.1	36	35	25	28	15	14
600 grit	6.5	30	30	23	23	14	12

Table 2 Mean slip resistance values (BPN) for a series of granites that had been honed or polished to different finishes.

In the case of **Figure 1**, it can be seen that where the honed marble is tested to AS 4586, it obtained a result of 35 BPN, which would just enable it to receive an X classification. This complies with the recommendation that is made in the Standards Australia Handbook 197: *An introductory guide to the slip resistance of pedestrian surface materials*, 1999, (refered to as HB 197) for the 'wet' portion of entry foyers in hotels, offices and public buildings. Although it is unlikely that the marble would have complied with the R10 oil-wet ramp recommendation that is also made for such areas in HB 197, the client did not commission such a test. CSIRO advises that products should comply with both recommendations rather than just one of them, as this provides a greater safety factor.

While CSIRO appends complimentary surface roughness reports to pendulum slip resistance reports, many clients fail to act on its advice:

> "BS 7976:2002, Pendulum Testers, requires a different test foot preparation (lapping paper) for pedestrian surfaces that have a Rz roughness of less than 15 microns. The lapping paper tends to reduce the pendulum result, sometimes appreciably. CSIRO recommends the use of this procedure (CSIRO COF1) as an adjunct to AS/NZS 4586. It helps to discriminate among products that have marginal slip resistance and to identify those that may be dangerous if wet".

The notional interpretation of: "contribution to the risk of slipping when wet" to the classification system of AS/NZS 4586:1999 was removed to avoid specifiers selecting products on dissociated speculation, rather than seeking the guidance material on specific usage situations that is offered in HB197. Class X products were identified as making a moderate contribution to the risk of slipping when wet.

The honed marble in **Figure 1** is likely to be quite slippery when wet, even if it did just manage to obtain an X classification (due to the roughness of the Four S rubber). If tested in the UK, the product would have received a result of 14 BPN, where the UK Slip Resistance Group Guidelines provide an initial interpretation of results of 24 BPN or less as having a high slip risk. The UKSRG Guidelines also draw attention to the need to consider other specific factors.

Comparative testing with CEN rubber

CSIRO used a TRL rubber (52 IRHD and 69 per cent resilience) and a CEN rubber (61 IRHD and 69 per cent resilience) to determine the slip resistance of a number of stones at 23°C and 50 per cent relative humidity. As **Table 2** indicates, there is generally not much difference between the results for the two rubbers, even though the TRL rubber failed to comply with the 53 IRHD minimum requirement. However, the method of preparing the rubber slider had a significant effect on the result. It should be noted that the samples only comprised four specimens and that there was considerable variation in most samples, such that the declared values would be lower.

Further results have been obtained for other stones. A highly polished granite with 2.0 Rz was very sensitive to rubber preparation. The honed marble shown in **Figure 1** was again found to be sensitive to CEN and TRL rubber preparation. A polished limestone with 1.7 μm Rz was sensitive to Four S rubber preparation but not to CEN or TRL rubber preparation. A honed limestone with 11.7 μm Rz was insensitive to rubber preparation. A fine-grained honed argillaceous sandstone with 13.6 μm Rz was sensitive to rubber preparation. The same stone, when bush hammered (69.6 μm Rz) was insensitive to rubber preparation.
Returning to the original enquiry, how was the slider prepared and is there an established convention within Europe as to how sliders should be prepared? The laboratory in question responded that they use any kind of stone that respects the clause's condition (the surface that is used to prepare the rubber slider must have a dry skid resistance value above 40 BPN). The three very different abrasive papers used in this CSIRO study all yielded results in excess of 100 BPN.

One British laboratory stated that they followed the BS 7976 protocol using 400-grade silicon carbide resin bonded paper when the stone has an Rz roughness greater than 15 μm, or the lapping film when it is equal to or less than 15 μm. They also state the rubber (TRL, CEN or Four S) used in their reports. EN 1341 requires that the report shall include: "any deviations, additions to or exclusions from the test specification, and any other information relevant to a specific test". This permits a laboratory to report the type of rubber used, the surface used to prepare the rubber slider and the temperature at the time of testing. Such information should preferably also be reported when testing to EN 14231, which permits the reporting of 'remarks'.

Another British laboratory reported using TRL rubber when testing to EN 1341 and preparing the slider on float glass. Another laboratory reported using lapping film, although this preparation takes slightly longer. However, while there are no right and wrong answers, coarser stones are likely to be far more effective at roughening the polished rubber than smooth stones are in polishing a coarse rubber. As there is not a uniform European convention for preparing sliders, the slip resistance results for smooth stones are thus likely to vary considerably.

Another aspect of the original enquiry relates to the marble having a minimum expected or declared value of 43 BPN. The six specimens had individual mean values of 44, 46, 45, 45, 47, 46 and 46, giving a sample mean of 46 BPN. EN 1341 requires that the mean value for the sample be reported. However, while the slip resistance conformity criterion states: "the results for all of the test specimens shall not be less than the declared value", the standard does not reveal how the declared value should be calculated. In the case of the French honed marble report, the minimum expected value has been obtained from the 5 per cent quantile using a 75 per cent confidence level. While such a statistical approach to the reporting of results is to be applauded and encouraged, it would be useful if a definitive method of calculation was given or referenced in the standard.

While it is possible that a TRL rubber was used to conduct the testing, and that the slider was conditioned on a stone that produced a roughness equivalent to that of grade 400 paper, it is still not known what the temperature was at the time of testing. AS 4586 (and BS 7976) both require the application of (slightly different) temperature corrections. If the laboratory was at 17°C, 1 BPN would be subtracted from the result. At 11°C, 3 BPN would be subtracted. A mean result of 46 BPN using the TRL rubber in accordance with AS 4586 would lead to a product just managing to obtain the highest pendulum classification, V. Past experience of honed marbles is that they do not have sufficient slip resistance to be given this classification. It would seem most unwise to assume that EN 1341 results can be converted to AS 4586 results, unless the report contains all the evidence required to justify such a conversion.

If we return to **Figure 1**, where the honed marble just managed to obtain an X classification, it would only obtain a Z classification if AS 4586 adopted the use of lapping film. One of the benefits of adopting the lapping film would be to remove questionable materials from classes X and Y. This would allow some recommendations to be based on class Y.

Standards Australia Committee BD-094 has decided, in principle, that most internal publicly accessible areas should be defined as wet, transitional and dry areas, with the proposed definitions being:

- **Dry areas:** those areas in which appropriate control measures ensure an area remains dry when in use.
- **Transitional areas:** those areas that are intended to be kept dry, such as by the provision of design features (awnings, drains, mats, air locks, etc.) appropriate to the physical location, climate and general exposure to water; and maintained in a dry and clean condition by the facility's manager.
- **Wet areas**: those areas that are not defined as a dry or transitional area, which may be either constantly or intermittently wet or otherwise contaminated.

It is quite possible that HB 197 might recommend class Y products for transitional areas if lapping film is adopted for preparing Four S sliders when testing smooth surfaces. The current recommendation is X. This would exclude the honed marble (in **Figure 1**) but would allow the use of some other products that do not currently obtain an X classification. There would inevitably be some disruption as smooth surfaced products would require testing. However, if such change improves public safety there should be considerable savings associated with a reduced involvement in potential litigation.

Such a significant change prompts the question: "Will AS/NZS 4586 be modified to permit the reporting of classes X, Y and Z when testing with TRL rubber" to enable more use to be made of the EN 1341, 1342 and 14231 test results? In the short term it is unlikely as there has been poor correlation between the wet pendulum results obtained using the Four S and TRL rubbers[2]. There may be better correlation if lapping film is used to prepare sliders, however, it appears that CEN/TC 246 needs to modify its slip resistance standards in order to ensure more consistent testing practices. They might also consider eliminating one of the rubbers, logically the CEN rubber if they are seeking to harmonise with other existing international standards. It is apparently made to a formula which might present problems if it is the same as giving 10 ladies a cake recipe: you may get 10 different cakes. TRL and Four S rubbers are reportedly more difficult to make because they are made to tight properties.

It should be noted that CEN Technical Committee 339 is working to harmonise the European slip resistance product standards. The current thinking is to have three reference tests based on the inclining ramp for

a) ordinary floors under shod traffic using Four S rubber and plain water, b) floors subject to barefoot traffic using bare feet and plain water, and c) industrial floors using the German boot and oil. The harmonised test will be a portable device which gives acceptable correlation to at least one of the three reference tests. Work at CSIRO and the UK Health and Safety Laboratory has shown that the pendulum gives good correlation against the first two reference tests when the Four S and TRL sliders are used respectively. However, this does not necessarily ensure that the pendulum will be adopted.

Harmonisation requires compromise, and there are differences. AS 4586 requires that products are tested in the direction expected to give the lowest result, while EN 1341 requires that each specimen be tested in two directions at 180 degrees to one another and that the mean of these results be reported. EN 1341, 1342 and 14231 have a calibration procedure and require that the pendulum be calibrated annually. While these standards do not require the use of any internal or external reference samples, it might be anticipated that this aspect should be satisfactorily covered where a laboratory is accredited to ISO 17025.

Grade 400 paper seems appropriate for preparing sliders when testing most stones and provides a means of validation in AS 4586. Lapping film is used as a means of validation in BS 7976. Lapping film should be used to prepare sliders when very smooth stones are to be tested, as it enables differentiation between the most slippery stones. In some quality control situations, it may be more appropriate to condition the slider on the stone and to reserve that slider for that specific stone finish.

Given the need to develop international standards to facilitate trade, Australia may need to drop the dry floor friction test method in favour of dry pendulum testing.

Most importantly, all counties should support CEN/TC 339 in its endeavours to develop an international standard for slip resistance, particularly if it facilitates suitable means of statistical analysis of results, whereby declared values should provide a realistic indication of the minimum traction available when products are installed. This would herald momentous progress.

This study has again confirmed the importance of rubber preparation. A co-efficient of friction is not a material characteristic: it is a system property that depends on the nature and condition of the rubber test foot. In recognising this, if we return to the original question, it would generally be unwise to rely upon European slip resistance reports for smooth surfaced stones as there is generally no way to reliably convert the results to the classifications that are used in AS 4586 and HB 197. There is at least one laboratory that provides sufficient information, where it may be possible if the result is high enough. While a high wet result, of say 75 or 80 BPN, is indicative of good slip resistance, in the majority of cases the best policy is to have the stone tested to AS/NZS 4586.

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(Footnotes)

[1] R Bowman, G W Quick, D A Devenish and C J Strautins, 'Practical aspects of slip resistance of stone', *Discovering Stone* Issue 2 , September 2002, p.16.

[2] R Bowman, C J Strautins, D A Devenish and T McEwan,'Practical aspects of slip resistance of ceramic tiles', *Tile Today* Issue 38, February 2003, p.20.