Health and Safety Executive

Novel slip characteristics of conglomerate tiles

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Research Report

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Novel slip characteristics of conglomerate tiles

Mr Rick Houlihan
Health and Safety Laboratory
Harpur Hill
Buxton
Derbyshire
SK17 9JN

The following report outlines the results of laboratory based slipperiness assessments to investigate the novel slip resistance behaviour of conglomerate tiles. All measurements were carried out using HSL standard procedures, in line with The UK Slip Resistance Group Guidelines where applicable.

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EXECUTIVE SUMMARY

The following report outlines the results of laboratory based slipperiness assessments to investigate the novel slip resistance behaviour of conglomerate tiles. All measurements were carried out using HSL standard procedures, in line with The UK Slip Resistance Group Guidelines where applicable.

Objectives

It has been noted from previous work that the slip potential of conglomerate stone floors can change significantly and rapidly during and after installation. Previous investigations have demonstrated a reduction of up to 35% in PTV (Pendulum Test Value) over 12 test repetitions on conglomerate stone surfaces. The principal aim of this study was to assess the pedestrian slip potential, via pendulum and surface microroughness analysis, of a selection of conglomerate floor tiles, from the ex-factory condition until consistent slip resistance results were achieved. The second aim was to ascertain the causes of this change, and to suggest methods or modifications to existing methods to enable accurate assessment of the slip resistance of new conglomerate floors.

Main Findings

This study found that the slip potential of many conglomerate stone floor tiles changed after comparatively little wear. Decreases of up to 30% in the measured slip resistance of floor surfaces in both dry and water-wet conditions were observed. Although this was a rapid change that tended to level out, it showed a difference between the ex-factory slip resistance and that of the installed floor. This could lead to duty holders having a false impression of the slip resistance of the floor under their management, potentially leading them to provide unsuitable control measures for the management of slip hazards.

*The rapid change measured on the **as-new** samples suggests that **ex-factory samples may give unsuitable slip test results**, and in order for duty holders to make a truly informed decision about the anti-slip performance of conglomerate flooring they need to obtain **pendulum data for the installed condition.***

Wherever possible flooring specification should be based on data generated from long term workplace trials to give a realistic impression of the slip performance of the flooring in-situ, and after installation and wear.

A relatively small difference in the PTV of a wet floor can make a significant difference to the control measures required to properly manage the floor to prevent pedestrian slip accidents. A suitable monitoring programme should be considered in all situations.

CONTENTS

1 INTRODUCTION

It has been noted from previous work that the slip potential of conglomerate stone floors can change rapidly and significantly during and after installation. The aim of this study was to assess the pedestrian slip potential, via surface microroughness analysis and Pendulum Coefficient of Friction (CoF) measurements, of a selection of conglomerate floor tiles.

Conglomerate stone floors are often laid in high pedestrian traffic indoor areas due to their aesthetic appearance, ease of maintenance and hardwearing nature. When selecting a floor, architects should consider slip resistance, but may not have an installed floor to assess, and will therefore make decisions based on manufacturers claims or tests of samples in ex-factory condition.

When conglomerates are installed they are often honed and finished in-situ, typically to a high polish, so the surface of a test sample will often not be representative of the installed product. This means that there may be an immediate difference in the level of slip resistance offered by the floor compared to the ex-factory condition of a test sample. With conglomerates being made up of several different types of stone set in resin, each of which will wear at different rates, and with a life expectancy of several decades, the slip resistance offered by the floor may be expected to be constantly changing.

There are three main ways that conglomerates may change.

i. To become smoother. As the traffic wears the roughness of the floor will become smoother and so the floor will become more slippery in wet conditions.

ii. To become rougher. As the floor becomes more worn the surface roughness increases and so it may give better slip resistance in wet conditions.

iii. For different parts of the floor to wear at different rates, leading to an uneven surface with an increased level of macro-roughness or texture.

Which happens is likely to depend on the installed finish, but is likely to be a combination of all three. This could lead to changes in the slip resistance of the floor. The issue, which this study hopes to resolve, is how to give an accurate assessment of the slip resistance of conglomerates, which will help specifiers to select floors with a realistic view of the long-term performance.

2 METHOD

Slip resistance assessments were generated in accordance with 'The Assessment of Floor Slip Resistance – The UK Slip Resistance Group Guidelines' (Issue 3, 2005). Two slip resistance test methods were employed, a 'Stanley' Pendulum Coefficient of Dynamic Friction (CoF) Test (see Figure 2.1), and a Mitutoyo SJ201-P surface microroughness transducer (see Figure 2.2). Both test methods are used routinely by HSL during on-site slipperiness assessments and contract research for HSE.

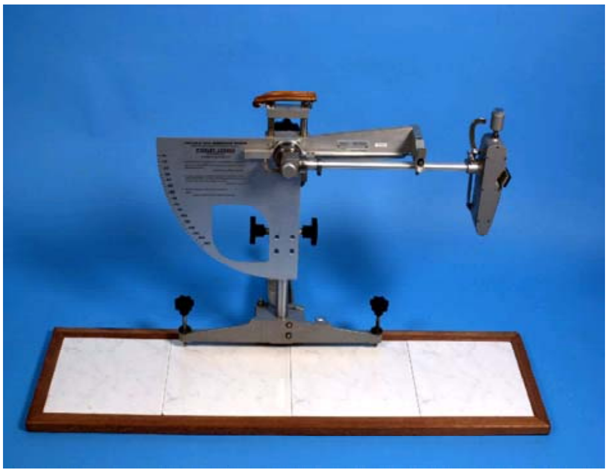


Figure 2.1. The 'Stanley' Pendulum CoF test

Figure 2.2. The Mitutoyo SJ-201P surface microroughness transducer

The test slider material used on the pendulum was Slider 96 Rubber, also known as Four-S Rubber (Standard Simulated Shoe Sole), developed to represent a footwear material of moderate slip resistance.

The Pendulum was calibrated by the British Standards Institution and slider preparation was carried out as per the UKSRG Guidelines. The Mitutoyo was calibrated against a UKAS roughness standard and checked in-situ using a calibrated roughness plate. Interpretations of pendulum and surface roughness data are based on the UKSRG Guidelines (Appendix A).

Samples for this investigation were sourced directly from manufacturers and from HSL's existing stock of as-new flooring samples.

3 RESULTS

A range of as-new flooring samples were studied under laboratory conditions using standard HSL / HSE techniques in accordance with the protocols outlined in BS 7976:2, 2000. Due regard was also given to the UKSRG guidelines where applicable.

3.1 SURFACE ROUGHNESS TESTING

Initial testing of each surface to assess the surface roughness was carried out using a calibrated Mitutoyo SJ201-P surface microroughness transducer. The following 11 roughness parameters were recorded:

Ra, Ry, Rz, Rq, Rt, Rp, RPc, Rmr, R3z, Rs and Rsm.

Definitions of these parameters can be found in Appendix B. The results of the roughness measurements can be found in Table 3.1. The results will be compared to pendulum CoF test results.

HSL Floor I.D.	Ra	Ry	Rz	Rq	Rt	Rp	Rpc	Rmr	R3z	Rs	Rsm
PED/05/119	0.71	8.58	5.67	0.98	8.75	1.60		69.3	3.20	37.60	
PED/06/182	0.40	5.54	3.64	0.57	5.67	0.83		85.0	2.16	31.40	
PED/06/183	0.57	4.30	4.30	0.77	8.01	1.06	229.92	78.3	2.36	33.90	45.1
PED/06/239	0.09	1.53	0.96	0.13	1.62	0.22		75.6	0.26	54.70	
PED/07/019	0.21	6.89	2.44	0.35	6.90	0.41		90.2		66.50	
PED/07/021	0.27	3.00	1.96	0.35	3.06	0.48		81.6	1.00	41.80	
PED/07/022	0.14	3.70	2.08	0.25	3.76	0.28		97.8	44.00	69.67	
PED/07/023	0.33	4.67	2.40	0.41	4.77	0.55		81.5	1.03	57.67	
PED/07/052	0.74	16.19	7.71	1.25	16.19	1.48		95.0		116.75	
PED/07/053	0.47	14.50	4.92	0.81	16.51	1.09		90.3		75.33	
PED/07/054	0.50	6.27	4.24	0.70	6.73	0.98		82.6	2.58	39.40	
PED/07/055	0.36	6.78	3.37	0.53	6.83	0.81		92.2	1.69	29.00	
PED/07/056	0.88	14.85	7.72	1.33	14.87	1.71		87.9	3.95	80.00	
PED/07/057	0.60	9.79	5.02	0.87	10.34	1.30		68.1		84.56	
PED/07/084	0.89	8.67	6.22	1.15	8.84	2.35		42.4	4.12	38.50	
PED/07/023 REV*	6.42	43.31	35.82	7.95	46.04	15.30	48.72	26.0	16.60	97.50	243.3

Table 3.1. Summary of surface microroughness results. Values are averaged over 10 readings. For some parameters, normally Rpc, R3z and Rsm, a full set of data is often not achieved (due to the level of roughness being overrange), but any values recorded are averaged and presented. *Rev indicates the reverse side of the sample

3.2 PENDULUM TESTING

Measurements of floor surface Pendulum Test Value (PTV) were made using a calibrated Pendulum slipperiness assessment instrument. Data was generated in the as-found, dry condition, and after application of low volumes of potable water to the flooring by hand-spray.

In addition to the standard procedure as outlined in BS 7976, the pendulum tests were repeated until the same PTV was achieved in 3 consecutive tests. Because the surfaces are shown to change, this procedure should give a more accurate indication of slip resistance than would be expected from the standard procedure, as it shows consistent values. The tile surface was wiped between each test to remove any residue from the surface.

The pendulum data is presented in Table 3.2. Rather than report all of the repetitions of each test, only the first and last set for each test are presented. The difference between these values is shown as "Diff". The number of repetitions needed to obtain consecutive results is shown as "Reps". Note that this method would normally therefore have a minimum of 3 repetitions for each test direction. The accepted test resolution of the pendulum test is ±2 PTV, so changes of 2 PTV or less should not be considered significant.

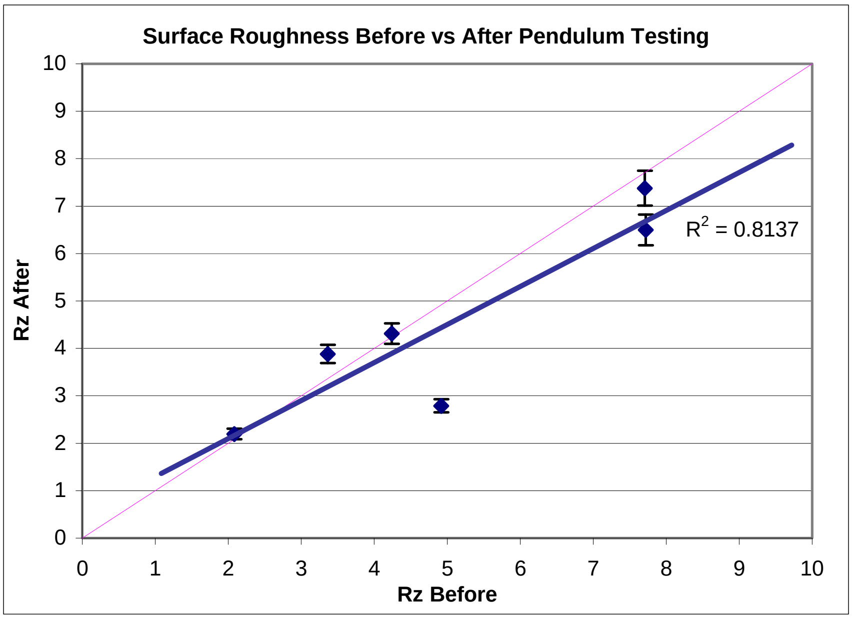
The upper table shows the data collected as part of this work. These samples also appear in Table 3.1. The lower part of the table summarises some work done previously by HSL. Roughness measurements were not taken on these surfaces and repetitive pendulum testing only carried out in the water-wet condition. These values are used where possible to add more data to the study.

		DRY				% change	WET				% change
HSL Floor I.D.	Rz	Start	End	Diff	Reps	Rise or Fall	Start	End	Diff	Reps	Rise or Fall
PED/05/119	6	63	61	-2	2	2.4	24	19	-5	7	21.4
PED/06/182	4	61	58	-3	9	5.3	13	11	-2	6	12.4
PED/06/183	4	60	56	-4	7	6.0	16	14	-2	5	10.2
PED/06/239	1	86	76	-10	10	11.5	6	5	-1	4	15.7
PED/07/019	2	81	79	-2	1	2.3	7	6	-1	5	15.2
PED/07/021	2	68	66	-2	3	2.5	7	6	0	4	2.0
PED/07/022	2	65	67	1	3	2.1	7	5	-2	9	33.0
PED/07/023	2	60	55	-5	7	8.5	7	7	-1	5	8.2
PED/07/052	8	87	60	-27	19	31.0	9	8	-1	5	11.1
PED/07/053	5	74	54	-20	15	27.0	7	5	-2	5	28.6
PED/07/054	4	55	52	-3	7	5.5	15	11	-4	5	26.7
PED/07/055	3	68	69	1	5	1.5	16	11	-5	6	31.3
PED/07/056	8	57	56	-1	5	1.8	14	10	-4	6	28.6
PED/07/057	5	67	61	-6	10	9.0	11	9	-2	6	18.2
PED/07/084	6	64	59	-5	10	8.0	42	26	-17	17	39.1
PED/07/023 REV*	36	65	67	2	10	3.1	64	63	-1	7	1.6
PED/05/118							30	20	-10	8	33.3
PED/05/119							24	17	-7	10	29.2
PED/05/160							24	17	-7	10	29.2
PED/05/172							37	24	-13	12	35.1
PED/05/174							30	24	-6	8	20.0

Table 3.2. Summary of wet and dry Pendulum test results. Also shown is % change between first and last result. Red indicates an increase in PTV, blue indicates a decrease. "Diff" = difference between initial and final result. "Reps" = number of repetitions before final result achieved. *Rev indicates the reverse side of the sample

The repeated testing showed an appreciable change in PTV on some of the surfaces. Conglomerates are designed to have a long service life in high traffic areas, so for the surface to be showing possible signs of wear with such a small amount of traffic as simulated by the pendulum test would be unlikely. As surface roughness and PTV are related, a change in one would normally be an indicator of a change to the other. Six tiles that showed a significant change in PTV, i.e., 20% or more, were selected and their surface microroughness was measured again after pendulum testing. Their values were compared to the initial measurements to see if any measurable difference in the surface roughness could be identified.

The results are shown in Figure 3.3. The error bars indicate variance set at ±5%, the tolerance of the Mitutoyo's daily calibration check.



	Rz	
Number	**Before**	**After**
PED/07/022	2.08	2.20
PED/07/052	7.71	7.38
PED/07/053	4.92	2.79
PED/07/054	4.24	4.31
PED/07/055	3.37	3.88
PED/07/056	7.72	6.50

Figure 3.3. Rz surface microroughness before and after pendulum testing. Pink line shows 1:1 relationship. Trend line shown in blue.

Most of the Rz values recorded after testing are similar (close to the pink 1:1 line) to the measurements made before pendulum testing. The most variation shown, i.e. the furthest point from the pink 1:1 line, indicates a decrease of 2µm, which may be accepted as within the measurement repeatability. Without this point on the graph (before = 5µm, after = 3µm) the trend line would be much closer to the pink 1:1 line and show almost no variance from a 1:1 relationship. At this range of Rz much change is unlikely; a change of 20% would be equivalent to Rz 10µm reducing to Rz 8µm; the extension of the trend line suggests that this may be a reasonable expectation.

With the exception of the testing on the unfinished reverse side of one of the tiles, the roughest surface tested was below Rz 10µm. What is unknown is whether the relationship observed would extend to rougher surfaces. A 20% change to a surface of Rz 40µm would result in Rz 32µm. For a surface to change by Rz 8µm with as much wear as is applied here would be very unlikely. However, what may be expected is that over the lifetime of the flooring the surface will gradually wear, and the slip potential will continually change.

A hybrid surface roughness parameter, Rp/Rs, has been found to correlate more closely with the PTV than Rz in some instances. An equivalent graph to Figure. 3.3 for this combined surface roughness parameter is given in Figure. 3.4.

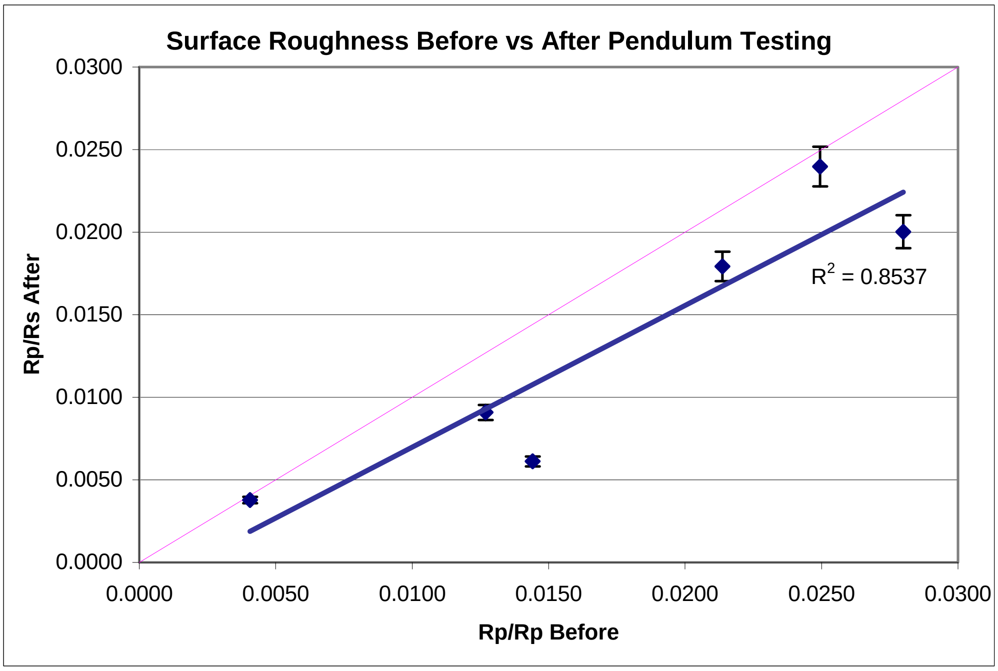


Figure 3.4. Rp/RS surface microroughness before and after pendulum testing. Pink line shows 1:1 relationship. Trend line shown in blue.

The R^2 value of the relationship shown in Fig. 3.4 is slightly higher than that shown in Fig. 3.3, indicating a closer fit of the data points to the trend line. The trend line is also closer to being parallel with the 1:1 indicator line, suggesting that a more consistent level of change of the roughness was achieved over the course of the testing. The result trend line is again below the 1:1 indicator line, showing a trend of decreased surface roughness after testing compared to before testing.

The maximum peak height, Rp, usually decreased and the mean spacing between peaks, Rs, tended to increase during testing. This is a likely consequence of microscopic peaks being smoothed, and leads to a significant change to the Rp/Rs value, in one case a reduction of over 50% was recorded (0.0144 before to 0.0061 after) but the trend line suggests an average reduction of 20%. This is in line with the values suggested for Rz roughness.

4 DISCUSSION

The results given in section 3 suggest that some as-new conglomerate tiles do change significantly over repeated testing. Table 3.2 shows that the recorded PTV can change by up to 27 points, or about 30%, over the course of 20 test repetitions in the dry condition. A similar relative change of up to around 30% can be observed in the wet condition over 6 test repetitions, although a change of up to 20% may be expected.

Obviously, the values are very different for dry and wet PTV. The pendulum test has an acceptable error margin of ±2 PTV, and 11 of the 21 tiles tested changed by less than 2 PTV in the wet condition. Many of the wet PTVs start in single figures, and so there is not much scope for change. Dry PTVs are frequently above 60 and so have greater scope to change by a significant value. 7 of the 16 tiles tested changed by 2 PTV or less in the dry condition.

The PTV changed by:

PTV	DRY	WET
0 ~ 2	7	11
3 ~ 5	3	2
5 ~ 10	3	6
10 ~ 20	1	2
20 ~ 30	2	0

%	DRY	WET
0 - 5%	7	2
5% - 10%	6	1
10% - 20%	1	6
20% - 30%	1	7
30% +	1	5

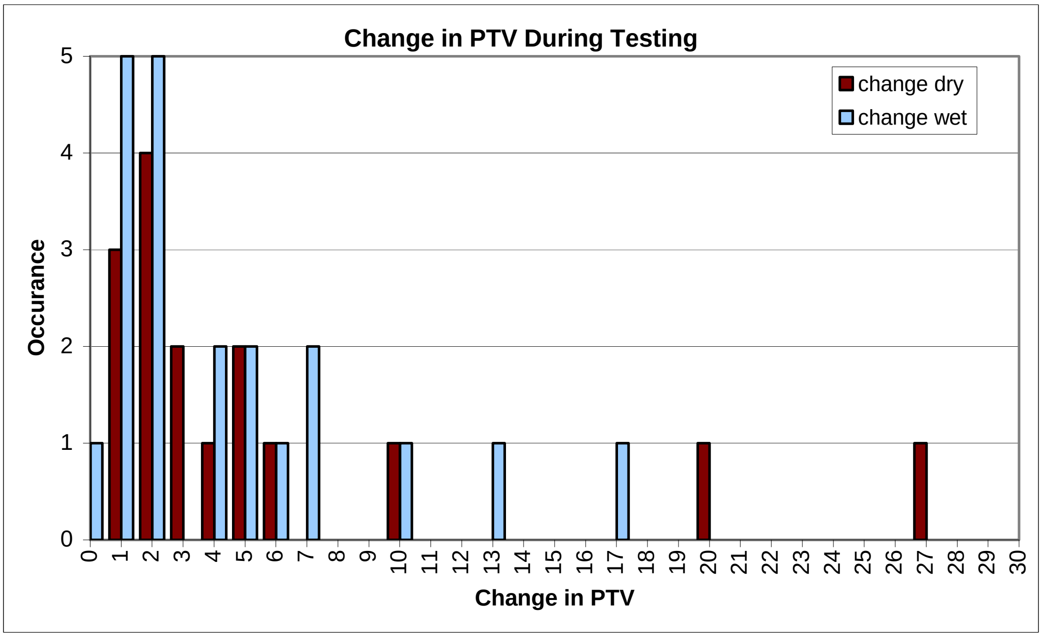


Figure 4.1. Change in PTV over the course of repeated testing. Pendulum tests were repeated until the same PTV was achieved in 3 consecutive tests

These values suggest that although the wet PTV is only shown to change by 0 to 5 PTV in the majority of cases, when considered as a percentage change in relation to the starting point, this accounts for a much greater difference. Over a third of the tiles tested changed by 20% or more in the wet over the course of the testing, and over three quarters changed by 10% or more. These values could indicate a significant change with regards the slip potential presented to the user. A 20% reduction of PTV and Rz surface roughness could significantly alter the slip resistance of an installed flooring surface, and may significantly alter the systems required to maintain the floor in a safe manner.

Given that both the initial and the final water-wet PTV often indicate a high slip potential, the controls that would be necessary on such floors may not necessarily change. This would however have a significant effect on the management of a surface that was specified as a low or moderate slip potential and was measured post-installation as a high slip potential. 4 of the samples tested changed sufficiently to change the slip potential classification in water-wet conditions. For example, PED/05/172, changed from PTV 37, a low slip potential, to PTV 24, a high slip potential, over the duration of the tests. This level of change in slip potential would necessitate significant changes to the management required to control the hazard and reduce the risk of pedestrian slip accidents.

A variety of tiles were tested, and so different results were expected due to differences between the materials, construction and finish. Several of the tiles were of a highly polished finish, many of which changed very little during testing. Surfaces of a more open-matrix finish tended to show more of a change. The significance of this difference cannot be easily determined during such a limited study. It may be that the smoother finished tiles take much more wear to be smoothed further and show a change in the PTV than rougher tiles. This seems sensible if the relationship between surface roughness and slip resistance is considered. A rougher surface would be prone to smoothing by wear, as the higher micro-rough peaks of the surface are smoothed. In contrast, a smooth surface may already lack these higher peaks, and so further smoothing would take significantly more wear.

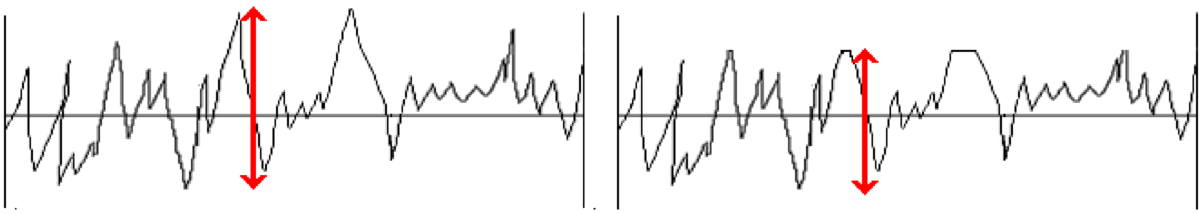


Figure 4.2. Schematic diagram of a simulated surface microroughness profile. The unworn trace is shown on the left with high peaks. The worn trace on the right shows the peaks worn and smoothed. Rz roughness range is indicated by the double-headed arrow in each case.

The schematic of a microroughness trace (Fig. 4.2) shows the high peaks of a rough surface (left) and the smoothed peaks of the same surface after wear (right). An indication of the Rz surface roughness is shown by the red arrow in each instance. This change in surface roughness tends to have the effect of decreasing the PTV in water-wet conditions, as there are less peaks able to break through a fluid squeeze film.

What is unclear is how long term wear affects the slip potential of these surfaces. One possibility is that the surface initially changes significantly but quickly (as demonstrated by some surfaces tested in this work), but then little further change occurs. Assessing these surfaces would be a simple case of following the test procedure used here - repeat testing until consistent values are achieved - resulting in a fair indicator of the floors slip resistance. However, this is unlikely. The more likely situation is a constantly changing surface, which may initially change significantly and quickly, but will continue to change throughout the lifetime of the floor. In this situation the surface would need regular testing to monitor the slip resistance of the surface.

5 CONCLUSION

The data generated suggests that the slip resistance of the flooring materials studied may change significantly and quickly. Installation alone, or a small amount of wear (by pedestrian traffic) may be enough to make this change. It is difficult to predict how these changes will manifest themselves without careful measurement.

The rapid change measured on the ***as-new*** *samples suggests that* ***ex-factory samples may give unsuitable slip test results****, and in order for duty holders to make a truly informed decision about the anti-slip performance of conglomerate flooring they need to obtain* ***pendulum data for the installed condition.*** *A suitable programme of monitoring the installed floor should also be considered.*

If possible, flooring specification should be based on long-term workplace trials to give a realistic impression of the slip performance of the flooring in-situ, and after it has been subjected to wear.

Further work to investigate the effects of greater levels of wear on slip resistance would be valuable. Accurately simulating wear of a flooring surface by pedestrians is not currently possible in laboratory conditions, although HSL are investigating the feasibility of equipment which may allow this in the future.

6 REFERENCES AND FURTHER READING

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APPENDICES

APPENDIX A – EXCERPTS FROM THE UKSRG GUIDELINES

Pendulum Test Value	**Potential for Slip**
0 to 24	High
25 to 35	Moderate
36 +	Low

Rz Surface Roughness*	**Potential for Slip**
Below 10	High
Between 10 and 20	Moderate
20 +	Low

*Roughness values applicable for water-wet, low activity pedestrian areas.

APPENDIX B – ROUGHNESS PARAMETER DEFINITIONS

Ra
Ra is the arithmetic mean of the absolute departures of the roughness profile from the mean line.

Ry
Ry is the distance between the maximum peak height (Rp) and the maximum valley depth.

Rz
Rz = Rp + Rv and is the mean value of the maximum peak to valley height of the profile within the sampling lengths.

Rq
Rq is the Rms parameter corresponding to Ra.

Rt
Total height of the profile. Rt is the maximum peak to valley height of the profile in the assessment (evaluation) length.

Rp
Maximum profile peak height. Mathematically the largest peak deviation of the roughness profile from the mean line within a sampling length. When more than one sampling length is analysed Rp is the mean value of the individual Rp values for each sample.

RPc
RPc is the peak count. It is the number of local peaks which project through a selectable band centred about the mean line.

Rmr
Rmr is the length of bearing surface (expressed as a percentage of the evaluation length) at a given depth below the highest peak.

R3z
R3z is the vertical mean from the third highest peak to the third lowest valley in a sample length over the assessment length.

RS
RS is the mean spacing between local peaks. (A local peak is an upward convex portion of an assessed profile which has concavities on both sides).

Rsm
Rsm is the mean spacing between profile peaks at the mean line, measured within the sampling length. (A profile peak is the highest point of the profile between an upwards and downwards crossing of the mean line).

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