Surface Roughness Slip Resistance And Relationship To Floor Cleaning

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Summary: Determination of slip resistance of flooring materials is of importance to both designers and specifiers when responding to client requirements, and to building owners, users and facility managers when buildings are commissioned and over the lifetime of the floor. Clearly, acceptable slip resistance of floorings is a significant safety requirement of any building with an industrial, or public service operation. Assessment can be made as a routine part of production, to ensure client satisfaction, or upon the floor in-service, to ensure the required slip resistance has been maintained during routine service life.

Slip resistance is commonly measured in the UK using the TRRL pendulum tester but the use of surface roughness measurement to assess slip resistance is growing in popularity. This paper identifies a relationship between the surface roughness of flooring materials and the cleaning properties by presenting two case studies. The BRE studies examined in-service floor tiles that were retaining dirt, irrespective of the cleaning regime, or the traffic. The relationship between surface roughness and dirt retention enabled the identification, in one case, of areas where the cleaning regime was insufficient.

Examination of the data produced from the two case studies suggests that the peak to valley distances of the sub-millimetre surface profile and the widths of the peak to valley elements are important parameters influencing dirt retention. These parameters can be measured using one of the instruments recommended in the Guidelines of the UK Slip Resistance Group (2000), although the measurement of the mean width peak to valley distances is not required when assessing slip resistance.

Thus, in addition to providing information concerning slip resistance, the assessment of sub-millimetre surface profile characteristics may also be advantageous in quantifying cleaning properties, and provide valuable information both before installation and during service life.

Keywords: Ceramic, terrazzo, slip, surface roughness, cleaning

1 INTRODUCTION

Determination of floor slip resistance is of importance to ensure the appropriate properties will be obtained for new floors or floors maintained in-service. Measurement of floor slip resistance is most commonly conducted in the UK using the TRRL pendulum tester, although the use of surface roughness measurements is growing in popularity. Recent studies at BRE have indicated that a relationship exists between the sub-millimetre surface profile characteristics and the cleaning properties of flooring materials. Thus, the movement towards roughness measurements to assess slip resistance may prove to have additional benefits in providing characterisation of the floor cleaning requirements. Although there is still much work to be completed to quantify this relationship this paper presents two case studies where a direct correlation between the sub-millimetre floor surface profile and the cleaning properties has been established. It is hoped that these data will assist others conducting research in this field.

2 MEASUREMENT OF FLOOR SLIP RESISTANCE

In the UK the pendulum tester is commonly used to assess the slip resistance of floorings both in-situ and in the laboratory. The assessment technique is discussed in guidance from the UK Slip Resistance Group (UKSRG, 2000), the BRE Information

Paper 10/00 (Yates and Richardson, 2000) and the CIRIA Report 184 (Gatfield, 1998). This method is currently under consideration as a European Standard (prEN 13036-4: 1997) to assess skid resistance. The pendulum tester relies on the measurement of the coefficient of friction between a rubber slider and the flooring to assess the resistance to slip. For assessment of flooring a Four S rubber slider is recommended for most floors and the results are categorised according to Table 1.

Table 1. Categories of slip resistance

Potential for slip	*Four S pendulum value*	*Rz surface roughness (mm)*
High	25 and below	Below 10
Moderate	25 to 35	Between 10 and 20
Low	35 to 65	Above 20 and up to 30
Extremely low	Above 65	Above 30

The recently published Guidelines from the UKSRG (2000) support the use of surface roughness measurements to assess slip resistance, by providing test methods for both on-site and laboratory testing. Although not recommended as a replacement for the pendulum test the surface roughness is considered important, particularly where water contamination is likely. Equally, the UK Health and Safety Executive (1997) recognise that both the friction between the floor and the shoe and the sharpness of the granular micro-surface peaks influence slip resistance.

3 MEASUREMENT OF SURFACE PROFILE CHARACTERISTICS

The Guidelines of the UKSRG (2000) recommend the use of the Taylor Hobson Surtronic 3+ or Duo roughness meter, to establish the slip resistance of the floor in-situ or in the laboratory. Surface profile is quantified by parameters that relate to certain characteristics of the surface, defined in BS ISO 4287: 1997. The parameters discussed in this paper include Ra, Rq, Rc and RSm. These parameters can be classified in three groups, according to the type of characteristic that they measure:

- Amplitude parameters: Are measures of the vertical displacements of the profile, essentially peak and valley measurements, for example Ra, Rq, Rc.
- Spacing parameters: Are measures of spacings of profile elements (the surface profile between a peak and adjacent valley), for example RSm.
- Hybrid parameters: These relate to both the amplitude and spacing of the surface profile elements.

3.1 Definition of surface profile parameters

The Mean Line is commonly used in surface profile characterisation and it is derived by the least squares method. In basic terms it is a line which bisects the profile such that the area above it and below it are equal and a minimum, as shown in Fig. 1.

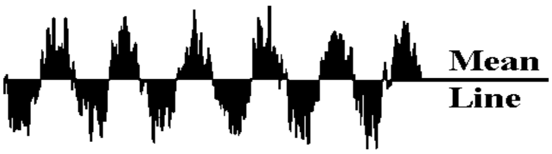

Figure 1. Mean line of a surface profile

The profile is described as a series of heights above or depths below the mean line, Z ordinates, at a distance along the sampling length, x ordinates, the ordinate value is written as Z(x). This is shown schematically in Fig. 2.

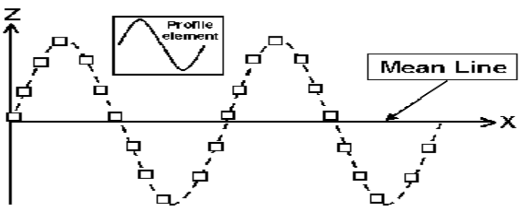

Figure 2. Z(x) ordinates of a surface profile

Ra is the average roughness of the surface and is the arithmetical mean of all the Z(x) values. Rq is the root mean square of these measurements, and thus is independent of the sign of the roughness (whether it is a peak or a valley) thus Rq is usually larger than Ra for the same sample set.

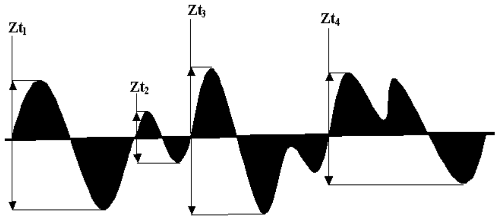

Figure 3. Schematic diagram of heights of profile elements (Zt_n)

Rz is the roughness parameter used in the UK Guidelines (UKSRG, 2000) to assess slip resistance, the threshold values are given in Table 1. This Rz value corresponds to Rc in BS ISO 4287:1997 and is the mean value of the profile element heights (Zt) within the sampling length as shown in Fig. 3.

Also discussed in this in this paper is RSm, the mean value of the profile element widths (Xs) within a sampling length (Fig.4).

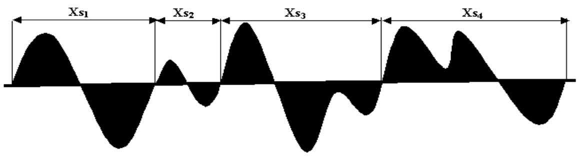

Figure 4. Schematic diagram of Xs

4 CLEANING PROPERTIES - CASE STUDIES

4.1 Case study 1 - Ceramic tiled floor

BRE were asked to examine the darkening of a ceramic tiled floor in a catering facility. BRE undertook an extensive study of the tile surface characteristics using optical and scanning electron microscopy (SEM) and laser profilometry in order to determine the causes of the darkening.

Optical and scanning electron microscopy of the tiles confirmed that the darkening was caused by dirt retention at the surface of the tiles, Figs. 5 to 8.

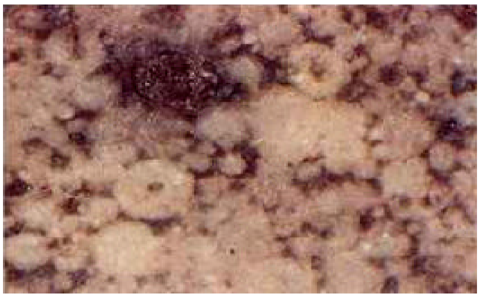

Figure 5. A severely darkened tile, optical microscope image X 150

Figure 6. A severely darkened tile SEM image, scale bar is 1000 mm

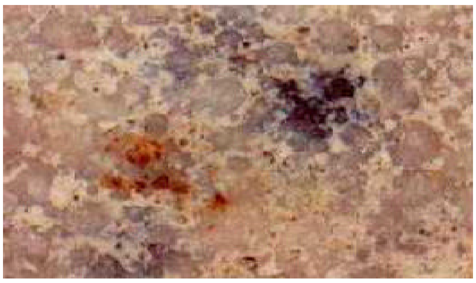

Figure 7. An unaffected tile, optical microscope image X 150

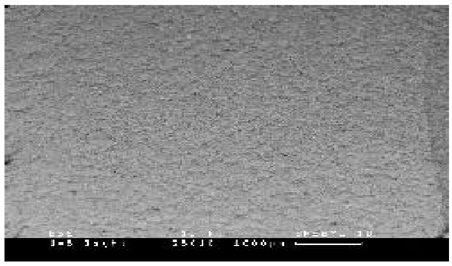

Figure 8. An unaffected tile SEM image, scale bar is 1000 mm

The optical micrograph (Fig. 5) shows the presence of the dirt at the surface of the darkened tile, which is absent in the unaffected tile (Fig. 7). This is confirmed as dirt of high carbon content by the dark appearance of this material in the back scattered electron SEM image (Fig. 6). Under the SEM lighter elements appear darker, thus carbon will appear darker than the surrounding alumino-silicate tile substrate. Few carbon-containing areas are visible on the unaffected tile (Fig. 8).

Surface profile was assessed for a number of tiles removed from different locations of the floor, subject to different cleaning regimes and traffic. The tile surface profiles were assessed using a Cyberoptics Microscan 3D laser profilometer. Measurements were taken at 10 different locations on each sample tile and then averaged to represent each tile. Surface scans were undertaken in 10 μm steps, each scan compromising 1000 steps, producing a sampling length of 10 mm. In this case study the samples were assessed for average Ra and Rq, given in Table 2.

No relationship was found between the cleaning regime in place and the darkening of the tiles (by visual assessment), the darkening being indicative of the quantity of dirt retained by the tile. These data are shown in Table 2, where 1 is the most rigorous cleaning regime and 6 the least rigorous (no pro-active cleaning under a disused conveyor belt). Table 2 also contains an assessment of the traffic the floor was subjected to at these points, where 1 is the heaviest traffic and 4 the lightest (no traffic under a disused conveyor belt). No direct relationship can be seen between the darkening and the traffic.

Table 2. Cleaning, traffic and roughness data for sample tiles

Area	*Visual description*	*Cleaning regime*	*Traffic*	*Ra (mm)*	*Rq (mm)*
7	Darkened	1	2	14	15
7	Unaffected	1	2	11	12
6	Little Darkening	2	1	14	15
6	Unaffected	2	2	11	11
6	Unaffected	2	2	11	11
3	Unaffected	3	3	12	12
3	Unaffected	3	2	12	13
5	Darkened	3	3	12	12
5	Darkened	3	3	12	12
8	Severely Darkened	4	1	22	25
8	Severely Darkened	4	2	17	19
1	Little Darkening	5	2	16	17
1	Little Darkening	5	3	13	14
1	Unaffected	5	3	13	13
1	Unaffected	5	3	12	13
1	Unaffected	5	3	12	14
2	Darkened	5	3	16	18
4	Unaffected	6	4	12	13
4	Unaffected	6	4	12	13

The relationship between the tile darkening due to dirt retention and the Ra and Rq values are given in Figs. 9 and 10. The graphs also show the $\pm$ 2 standard deviation values taken from the average of the 10 assessments on each sample tile. These error bars show that there is some overlap in the 95% confidence limits of the average measurements of the tiles retaining dirt and the unaffected tiles. This overlap does not affect the conclusions drawn from this case study but indicates that further data collection and analysis would be required before specification of a threshold roughness related to dirt retention could be established.

Figures 9 and 10 demonstrate the relationship between the roughness of the tile surface and dirt retention. In all but two examples is the dirt retention accompanied by higher surface roughness of the tiles. For these two exceptions, it is likely that the cleaning regime (Number 3) is not sufficiently rigorous, or that is it not conducted adequately. This example demonstrates that the use of surface roughness measurement will differentiate between causes of dirt retention.

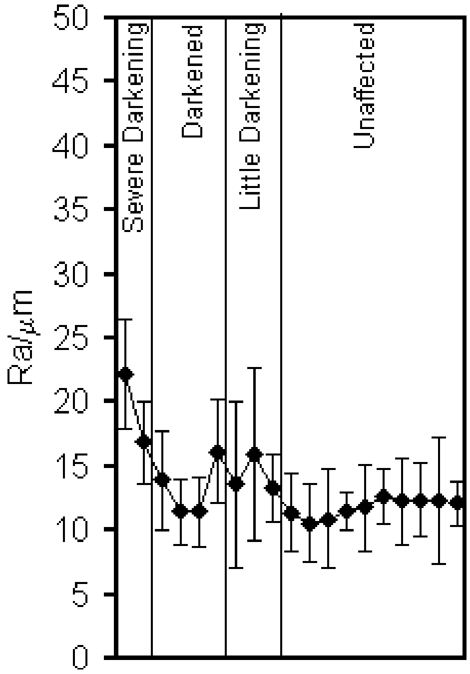

Figure 9. Ra vs visual assessment

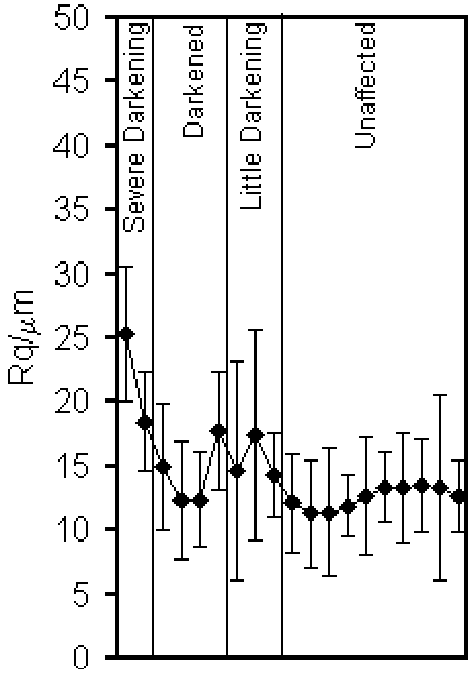

Figure 10. Rq vs visual assessment

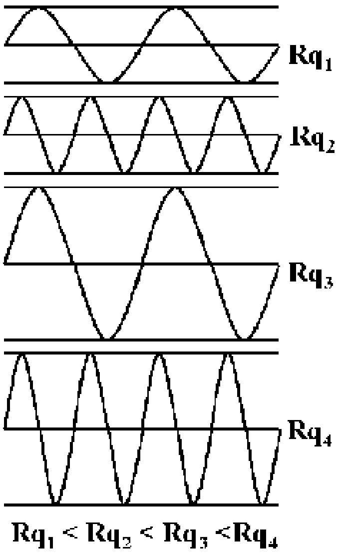

Figure 11. Impact of increasing Zt and reducing Xt on Rq

As the Rq values of the tiles retaining dirt are higher than those of the unaffected tiles it can be deduced that either the distance between the peaks and valleys (Zt, Fig. 3) has increased or the width of the profile elements has decreased (Xs, Fig.4), or both. This deduction is shown schematically in Figure 11, although in all cases the arithmetical mean (Ra) would remain identical.

4.2 Case study 2 - Terrazzo tiled floor

BRE were commissioned to investigate the dirt retention in the terrazzo tiled floor of a covered shopping mall. The areas that were retaining dirt appeared rougher (visually) than the other areas of the floor. A Taylor Hobson Surtronic 3+ was used to assess the mean roughness values Ra and Rq, the mean peak to valley distance Rc (Fig. 3), and the mean width of the profile elements RSm (Fig. 4). Rc measurements were taken although there was no implication that the slip resistance of the floor was inappropriate for the situation.

The surface measurement was conducted in-situ upon tiles retaining dirt and those that were in routine service but presented no difficulty in cleaning. The cleaning regime in all these areas was considered to be identical. The average of the data collected (10 measurements per tile) for 5 tiles, is presented in Table 3, along with a visual description of the tile surface.

Go Back
Next Page

Table 3. Data for terrazzo tiles

Tile Number	*Visual Assessment*		*Ra (mm)*	*Rq (mm)*	*Rc (mm)*	*RSm (mm)*
	Cleanliness	*Surface*				
1	Dirty	Rough	5.7	7.8	31.3	495.5
2	Clean	Smooth	1.7	2.3	12.1	207.5
3	Dirty	Rough	6.3	8.9	30.6	516.7
4	Clean	Smooth	1.7	2.4	11.0	226.9
5	Dirty in Places	Partially Rough	5.7	7.8	29.2	514.2

The data in Table 3 confirms that all the tiles have at least moderate slip resistance (categories given in Table 1) and that the tiles that appear visually rough and that are retaining dirt are quantifiably rougher than those that appear smooth and are unaffected by dirt retention.

Taken collectively, the results presented in Table 3 indicate that, on average, the peaks to valley distances are larger (Rc is larger) and at further widths (RSm is larger) for the rough tiles that retain dirt, compared to the smooth tiles which are easy to clean. This is represented in Fig. 12.

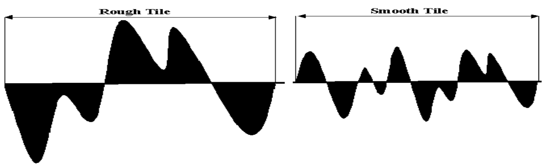

Figure 12. Schematic diagram of rough and smooth tiles in shopping mall

Figure 11 demonstrates that a decrease in the mean width of profile element (RSm) or an increase the peak to valley distance (Rc) will result in a increase the root mean square roughness (Rq). Equally an increase in RSm or a decrease in Rc will result in a reduction in Rq. Thus the combination of the increased Rc and increased RSm, results in smaller changes in Rq.

Hence the difference between the Rq for the rough, dirt retaining tiles and the smooth, unaffected tiles (Table 3), although apparent, is less obvious than the differences between the Rc and RSm. This suggests that the measurement of Rc and RSm may be more appropriate when characterising the cleaning properties of surfaces.

Figures 13 and 14 contain the Rc and RSm averages, with 95% confidence limits (+ 2 standard deviations), plotted against the visual assessment of roughness, indicative of dirt retention. As with the previous case study there is some overlap in these confidence limits, again indicating that more data is required before threshold roughness values for Rc and RSm related to dirt retention can be established. The large 95% confidence limits associated with the partially rough tile result from the variation in the in roughness across the tile surface.

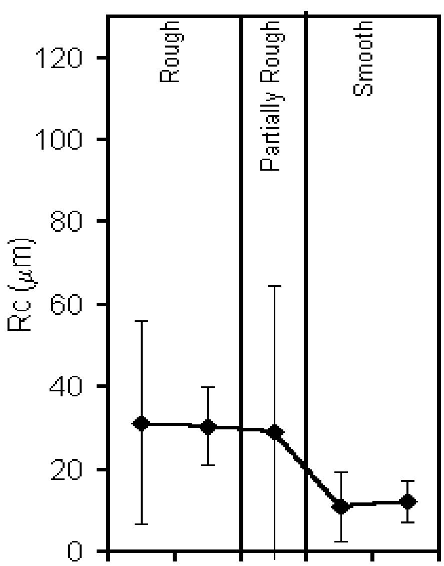

Figure 13. Rc vs visual assessment

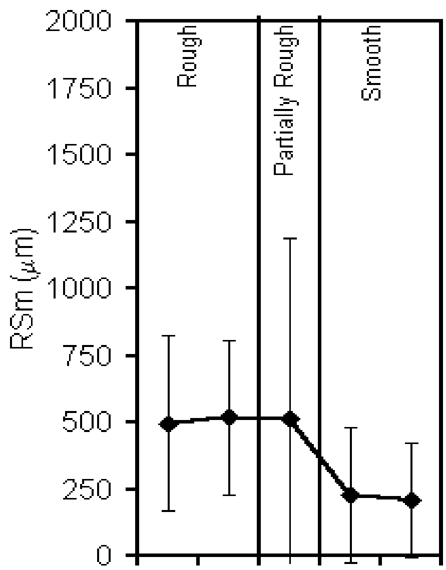

Figure 14. RSm vs visual assessment

Go Back

5 CONCLUSIONS

The relationship between sub-millimetre surface profile and slip resistance is recognised as important and measurement of surface roughness recommended as a tool to assess slip resistance in areas subject to water contamination. The case studies presented here indicate a relationship between the surface profile and dirt retention although there is a requirement for more data before this relationship can be fully quantified. However, the evidence from the studies presented here suggests that the relationship between the peak to valley distances (Zt, Rc) and the width of the peak to valley profile elements (Xs, RSm) are both of importance in dirt retention.

Thus, in addition to providing information concerning slip resistance, the assessment of surface profile characteristics, may also be advantageous in quantifying cleaning properties, and provide valuable information both before installation and during service life.

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