Health and Safety Executive

Suitability of Slider 55 rubber for use as a standardised slider material for the simulation of barefoot pedestrians

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Suitability of Slider 55 rubber for use as a standardised slider material for the simulation of barefoot pedestrians

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Slider 55 rubber has been used by the United Kingdom Slip Resistance Group (UKSRG) with the Pendulum Test to simulate the slip resistance characteristics of a barefoot pedestrian, when assessing floor surfaces for use in shower areas, changing rooms and swimming pools. The aim of this study was to investigate the suitability of Slider 55 rubber for this purpose.

A market survey was carried out, in order to source a representative range of surfaces typically used under water-contaminated, barefoot conditions. Surfaces were selected that would potentially present a range of slip resistance when under test. This included both ceramic and vinyl surfaces, which were both profiled and non-profiled. The slip resistance of each of the floor surfaces was assessed according to the HSL Ramp Test, using four operators.

Before pendulum measurements were carried out on the test surfaces, the effect of the pendulum slider preparation procedure on the pendulum test values measured was investigated. Three verification surfaces were used in this investigation; float glass, vitrified ceramic and Pink Lapping Film (PLF).

To assess the applicability of the pendulum test method with the Slider 55 rubber, to water-contaminated, barefoot conditions, the pendulum test measurements were compared with slip resistance measurements made with the HSL ramp test.

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KEY MESSAGES

Slider 55 rubber has been used with the pendulum slip resistance test to measure the slip resistance of a floor surface under the barefoot condition in forensic investigations for some time. Limited research has been carried out to support its use as an indicator of barefoot slip resistance. The suitability of Slider 55 rubber for use with the Pendulum slip resistance test in the assessment of floor surfaces subject to barefoot pedestrians has been investigated in this study.

An investigation of the effect of the pendulum slider preparation method for Slider 55 rubber showed that reconditioning the Slider 55 working edge with 20 swings across the P400 silicon carbide abrasive paper, followed by 20 swings across the wet pink lapping film (PLF) results in a more consistent pendulum test value (PTV) than reconditioning by 3 swings across the P400 paper followed by 20 swings across the PLF. Results on the vitrified ceramic tile and PLF verification surfaces suggest that the PTV is more consistent after the first or second reconditioning.

The measurements of slip resistance according to the ramp test method has indicated that the friction properties of operators' feet can differ significantly under water-contaminated, barefoot conditions.

The Slider 55 pendulum measurements for the ceramic tiles included in the study agreed reasonably well with the lowest or worst case measurement of slip resistance according to the Ramp test.

EXECUTIVE SUMMARY

Slider 55 rubber has been used by the United Kingdom Slip Resistance Group (UKSRG) with the Pendulum Test to simulate the slip resistance characteristics of a barefoot pedestrian, when assessing floor surfaces for use in shower areas, changing rooms and swimming pools. The aim of this study was to investigate the suitability of Slider 55 rubber for this purpose.

A market survey was carried out, in order to source a representative range of surfaces typically used under water-contaminated, barefoot conditions. Surfaces were selected that would potentially present a range of slip resistance when under test. This included both ceramic and vinyl surfaces, which were both profiled and non-profiled. The slip resistance of each of the floor surfaces was assessed according to the HSL Ramp Test, using four operators.

Before pendulum measurements were carried out on the test surfaces, the effect of the pendulum slider preparation procedure on the pendulum test values measured was investigated. Three verification surfaces were used in this investigation; float glass, vitrified ceramic and Pink Lapping Film (PLF).

To assess the applicability of the pendulum test method with the Slider 55 rubber, to water-contaminated, barefoot conditions, the pendulum test measurements were compared with slip resistance measurements made with the HSL ramp test.

Main Findings

An investigation of the effect of the pendulum slider preparation method for Slider 55 rubber showed that reconditioning the Slider 55 working edge with 20 swings across the P400 silicon carbide abrasive paper, followed by 20 swings across the wet PLF results in a consistent working edge to the pendulum slider, and thus repeatable measurement of the PTV.

Results on the vitrified ceramic tile and PLF verification surfaces suggest that the PTV is more consistent after the second reconditioning.

A lower level of repeatability was found with 3 swings on the P400 paper followed by 20 swings on the PLF.

Ramp test measurements gave a wide range of values for the ceramic tiles. The pendulum test results were found to agree reasonably well with the lowest, or worst case, measurements.

Closer agreement between the two tests was obtained on surfaces incorporating a profile or macroscopic surface texture.

Surfaces incorporating a profile, both ceramic and vinyl, presented a low slip potential, according to the HSL ramp test under the water-contaminated, barefoot condition.

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1. INTRODUCTION

The occurrence of slips in routinely wet areas used by barefoot pedestrians, such as swimming pools or changing room areas, is common. Measurement of the slip resistance of floor surfaces used in areas subject to barefoot pedestrian traffic needs to accurately replicate the tribology between the floor surface and human foot, including the effect of contamination, in order to present a reliable assessment of the slip risk.

The Health and Safety Laboratory (HSL) currently prefer two test methods to assess the slip resistance of floor surfaces. The first is the HSL ramp test, which is a laboratory-based test. This involves a human operator carrying out a series of closely controlled walks over a sample of floor surface positioned upon an inclinable platform and subject to the application of a contaminant. The inclination of the platform is gradually increased until the operator can no longer maintain a safe gait or experiences a slip. The Coefficient of Friction (CoF) is derived from the angle of inclination at which a slip occurs. The second test is the TRL Pendulum, which is a portable instrument, where the slip resistance of a floor surface is indicated by the loss in energy of a spring-loaded sample of rubber, attached to a weighed arm, as it is drawn across a floor surface as the pendulum arm swings through an arc.

The requirements of the pendulum test are detailed within the three parts of the British Standard BS 7976: 2002, with additional guidance given within the United Kingdom Slip Resistance Group Guidelines (UKSRG, 2005). There are currently two different types of rubber defined within BS 7976-1: 2002, and the UKSRG Guidelines, for use in the measurement of the floor surface slipperiness of pedestrian surfaces with the pendulum. Slider 96, also known as Four-S (Standard, Simulated Shoe Sole) rubber, is a material developed to be representative of shoe soling material of moderate slip resistance. Slider 55, also known as TRL or TRRL rubber, is a softer rubber compound used to simulate barefoot slip resistance.

The TRL Pendulum was originally designed for the measurement of skid resistance of road surfaces. A slider rubber with specific physical characteristics of resilience and hardness was selected to provide the necessary consistency in measurement performance. The Slider 55 rubber compound was originally used for this purpose. The UKSRG has for some time suggested the use of Slider 55 with the Pendulum, in order to simulate the interaction between the human foot and a floor surface in areas subject to barefoot pedestrian traffic, such as showers and changing rooms, or areas surrounding swimming pools. In 2002 Bowman et al published a limited comparison of test methods, which included both the pendulum test with TRRL rubber, and a barefoot ramp test method (Bowman et al, 2002). This was the result of a small number of investigations by HSL in such areas, which have been subject to slip accidents involving barefoot pedestrians. As such, the use of Slider 55 rubber to represent the barefoot condition has almost become routine, though little research has been carried out to support the use of Slider 55 rubber as a suitable indicator of barefoot slip resistance.

The work presented in this report was carried out to investigate the suitability of Slider 55 as a standardised slider material for the measurement of slip resistance in areas subject to barefoot pedestrian traffic. The aim of the work was to establish the relationship between the slip resistance measurements of the pendulum test using Slider 55 rubber and barefoot slip resistance measurements, using the HSL ramp test.

2. METHODOLOGY

2.1. THE PENDULUM TEST AND VERIFICATION MEASUREMENTS

The TRL Pendulum (Figure 2.1) is a portable instrument used to assess floor surface slip resistance. During a measurement a weighted pendulum arm (4), which rotates about a spindle at the pendulum head (11), is released from a horizontal position via a release mechanism (10). A sample of prepared test rubber (known as a slider), attached to the pendulum arm by the slider assembly (5), is drawn a fixed distance of 126±1mm across the test surface (7), as the arm swings through an arc (from right to left in Figure 2.1). The loss of energy experienced by the pendulum arm as the slider passes across the test surface is indicated by the height the arm reaches during the upward phase of the swing. A pointer (3) indicates the measurement result, known as the Pendulum Test Value (PTV), upon a scale (1). The PTV is closely related to the Dynamic Coefficient of Friction (which is a measure of the frictional force necessary to maintain sliding, and is a ratio of the frictional (or shear) force to the normal load). The PTV is expressed as a measure of slip resistance, as the test is normally carried out on surfaces under the contaminated condition.

A test comprises of 8 pendulum measurements across a surface, with the first three PTVs disregarded, and a mean PTV calculated from the remaining 5 values. Tests are carried out in three different directions when assessing a floor surface. This is in order to establish any directionality in the slip resistance, i.e. find the direction in which the slip resistance is lowest. The second test direction is usually in a direction at 90° to the first, with the third test direction at 45° to the previous two.

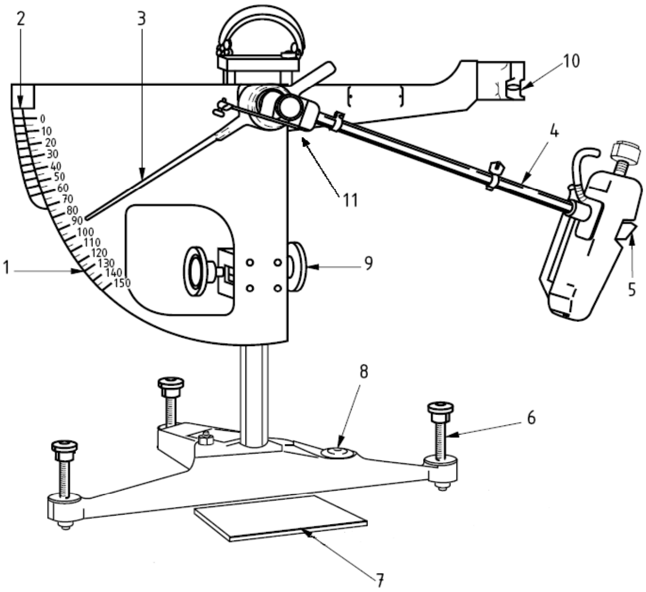

Figure 2.1. The TRL Pendulum CoF test. (Diagram adapted from BS 7976-1:2002 Pendulum testers – Part 1: Specification).

BS 7976 1-3: 2002 and the UKSRG Guidelines define two different rubbers for use as slider materials, which are identified by their IRHD hardness values. Slider 96 (also known as four-S) is a rubber developed by the UKSRG to represent a soling material of moderate slip resistance, and therefore, improve discrimination between floor surfaces of moderate to poor slip resistance when assessed using the pendulum. Slider 55 (also referred to as TRL or TRRL rubber) is a softer compound, originally developed for measuring the skid resistance of road surfaces, and is used to provide an indication of the slip resistance of a floor surface under barefoot conditions.

The pendulum test is carried out in accordance with the British Standard BS 7976-2:2002, where applicable, and the recommendations of the UKSRG Guidelines. The method requires the pendulum slider to be conditioned on two surfaces before each series of measurements are made. The slider edge is prepared as if carrying out a slip resistance test, by passing it across P400 grit, silicon carbide abrasive paper as the pendulum arm swings through an arc. If the slider has not previously been prepared, 20 swings across the P400 grit abrasive paper are necessary. This produces a 1-2mm working edge on the slider. If the slider has previously been prepared, a minimum of 3 swings across the P400 grit abrasive paper are necessary to re-prepare the working edge for use. A further 20 conditioning swings on a 3μm grade aluminium oxide lapping film (pink lapping film or PLF) in the water-wet condition attempts to produce a smooth, consistent finish to the slider edge before testing a surface.

Conditioning the working edge of the sliders with P400 grit, silicon carbide abrasive paper produces a significant amount of debris. For the harder, slider rubber compound, Slider 96, this debris is easily removed by the conditioning with the lapping film. But, for the softer compound, Slider 55 rubber, the conditioning procedure leaves the working edge subject to burring or debris attached to the working edge of the slider, which isn't removed in a consistent manner by the further conditioning on the lapping film.

It is believed that the small amount of debris left attached to the working edge of a Slider 55 rubber slider after the conditioning procedure can affect the verification measurements on the lapping film surface. Before pendulum measurements of the slip resistance of the surfaces under study were carried out, the consistency of the conditioning procedure and the effect on the repeatability of the verification measurements was investigated.

A verification test is carried out on two specified surfaces with known PTVs, in order to check that the Pendulum is operating correctly. This is normally done each day before use. A test is carried out in a single direction on each surface in the water-contaminated condition. The mean PTV measured should be within the tolerance limits of the PTV specified for each surface.

There are currently two surfaces specified within BS 7976-2:2002 and the UKSRG Guidelines to validate the Pendulum. A float glass surface of very low surface roughness, which presents a PTV in the range 5 to 10, and the same 3M™ 216X 3μm Imperial Lapping Film surface (PLF), as used in the slider conditioning procedure described above. (PLF is an A4 sheet of polyester film coated with a graded aluminum oxide layer. Its uses include polishing fibre optics.) The UKSRG is currently evaluating a third verification surface- a fully vitrified ceramic tile. This has been included in these verification checks.

A new sample of Slider 55 rubber was prepared in accordance with the procedure described above, i.e. 20 conditioning swings on the P400 grade, silicon carbide abrasive paper and 20 conditioning swings on the water wet lapping film surface. Additionally, a knife was used to remove debris from the working edge of the slider after the 20 conditioning swings on the P400 grade abrasive paper. Pendulum tests were then carried out upon the float glass surface, the lapping film and the fully vitrified ceramic surface, mentioned previously, under the water contaminated condition. The same working edge of the slider was then reconditioned in the same way, and tests upon the same three verification surfaces repeated. Repeat conditioning and verification tests were carried out until five measurements of the mean PTV for each of the three verification surfaces was obtained. The sequence of tests was repeated on the lapping film and the vitrified ceramic verification surfaces using a second new slider. This was in order to study the repeatability of the PTVs obtained.

BS 7976-2:2002 and the UKSRG Guidelines outline a procedure for re-preparing a worn slider edge, by carrying out a minimum of three swings of the slider across a P400 grade abrasive paper, followed by 20 conditioning swings across the PLF under the water-contaminated condition. In order to study the reproducibility of the PTVs obtained, the second working edge of the original slider was initially prepared as described above. Pendulum tests were then carried out on the lapping film and the fully vitrified ceramic surface, as previously. The working edge of the slider was then re-prepared by carrying out 3 conditioning swings on the P400 grade abrasive paper, followed by 20 swings on the water-contaminated lapping film. Again, Pendulum tests were carried out on the lapping film and the vitrified ceramic surface. This re-preparation and verification measurement sequence was repeated until 10 PTVs for both the lapping film and the vitrified ceramic surface had been obtained.

2.2. FLOOR SURFACES

Eleven floor surfaces were sourced for measurement of slip resistance in the barefoot condition. Surfaces were selected that would potentially present a range of slip resistance, from low to high slip potential, when under test. Surfaces were chosen that are sold for use in routinely wet areas, and where possible, those sold for use in areas where they would be subject to barefoot pedestrians. This included both ceramic and vinyl surfaces, which were both profiled and non-profiled. Table 1 lists the surfaces selected for testing, along with details of the type of surface and any relevant slip resistance information provided by the manufacturer.

DIN 51097 is a German ramp test method for the testing of floor coverings intended for use in wet, barefoot areas. This is a laboratory based test method, which involves a human operator carrying out a series of closely controlled walks over a sample of floor surface positioned upon an inclinable platform and subject to the application of a contaminant. The inclination of the platform is gradually increased until the operator can no longer maintain a safe gait or experiences a slip. This test is very similar to the HSL ramp test method, described within Appendix A, but uses sodium lauryl sulphate solution (NaLS), (that is, soapy water) as the contaminant instead of potable water. Surfaces tested according to this standard receive a quality group classification according to the mean angle of inclination achieved, A for angles $\geqslant$ 12°, B for angles $\geqslant$ 18°, and C for angles $\geqslant$ 24°.

BS EN 13845:2005 is a ramp test method for testing the particle based enhanced slip resistance of polyvinyl chloride (PVC) floor surfaces. This test is carried out with Slider-96 soled footwear, in order to assess the slip resistance performance of a floor surface under shod conditions, or testing is carried out in the barefoot condition. This test also uses sodium lauryl sulphate solution as the contaminant, where water is considered as more representative of a common workplace contaminant. This test classifies floor surfaces as slip resistant if they achieve angles of 20° or greater, for footwear (Esf), or a barefoot classification (Esb) is received if the surface achieves an angle of 15° or greater.

A sample of each of the floor surfaces shown in Table 1, approximately 1.0m in length and 0.5m in width, was laid on a marine plywood board base, in order to test each surface according to the HSL ramp test method and the pendulum test.

Each ceramic surface was laid using a flexible, waterproof adhesive, which was specifically aimed for use on wooden substrates. Tiles were laid without spacers, so that the tiles could be positioned as close together as possible. This was in order to reduce the interaction between the barefoot of the operator and tile joints or grouting lines of the ceramic surface.

A suitable waterproof, epoxy, vinyl adhesive was used for bonding the vinyl surfaces to the marine board base.

Table 1. Details of the floor surfaces selected for testing, including relevant slip resistance information from the manufacturer's literature

Surface (I.D.)	*Description*	*Barefoot Slip Classification*	*Angle**	*CoF**
Smooth, rigid surfaces				
1 (PED/10/138)	Smooth, unglazed ceramic tile (150x150mm), R_z = 8.45μm			
2 (PED/10/132)	Smooth, matt ceramic tile (146x146mm), R_z = 12.73μm	A (DIN 51097)	⩾12°<18°	0.21 - 0.32
3 (PED/10/13)	Smooth, vitrified ceramic tile (400x400mm), R_z = 12.72μm			
4 (PED/09/392)	Smooth, sanitary grade acrylic sheet for BS 8445 (1000x500mm), R_z = 0.14μm			
Rigid, profiled -surfaces				
5 (PED/10/135)	Square profiled, unglazed ceramic tile. Barefoot area use. (Reverse side of PED/10/138), R_z = 8.34μm			
6 (PED/10/136)	Chequer profile, unglazed ceramic. Barefoot area use (150x150mm), R_z = 34.00μm			
7 (PED/10/134)	Diamond studded profiled ceramic. (146x146mm), R_z = 31.12μm	C (DIN 51097)	⩾24°	⩾0.45
Vinyl surfaces				
8 (PED/08/303)	Studded profiled vinyl. R_z = 13.53μm	Esb (BS EN 13845)	⩾15°	⩾ 0.27
9 (PED/10/153)	Textured vinyl (with cork). R_z = 21.08μm	C (DIN 51097)	⩾24°	⩾0.45
10 (PED/10/154)	Studded profiled vinyl, Rz = 14.66μm	C (DIN 51097)	27°	0.51
11 (PED/06/282)	Smooth vinyl, R_z = 13.56μm			

**Where applicable, the angle and Coefficient of Friction shown refer to the respective test method displayed in the slip resistance information column.*

2.3. ESTABLISHING BASELINE BAREFOOT SLIP RESISTANCE DATA

Baseline Coefficient of Friction data was generated according to the HSL ramp test under the barefoot condition on each of the floor surfaces detailed in Table 1. Testing was carried out under the water-contaminated condition. The water applied to the floor surfaces was maintained at a temperature of 30±5°C for all tests. Prior to each set of 12 walks, each operator soaked their feet in water at a temperature of 30±5°C, for a period of approximately 10 minutes.

Each ramp operator carried out a set of 12 walks on an acrylic sheet surface in the water-contaminated, barefoot, condition prior to each day's testing. This procedure also served as a useful exercise to check the barefoot walking technique of each operator.

Where necessary, data was generated by more than two operators, and repeat testing of some floor surfaces was carried out a number of times, in order to ensure that a reliable measurement of the floor surface slip resistance was obtained. To prevent injury to the operator, testing was stopped when the operator reached an angle of 25° without a slip occurring, and a value of >25° was recorded. Further details of the HSL ramp test method are included within Appendix A.

2.4. PENDULUM TESTING OF FLOOR SURFACES

Measurements of floor surface PTV were made using a pendulum, calibrated by the British Standards Institute, on each of the sample surfaces constructed for testing on the HSL ramp test (as detailed in Table 1). The pendulum slider material used was Slider 55. Each surface was tested in accordance with BS 7976: 2002, where applicable, and the UKSRG Guidelines, as described previously. Tests were carried out in three different directions, with the first direction parallel to the walking direction of the sample, as if tested according to the HSL ramp test method. Testing was carried out in both the dry and water-contaminated conditions. Testing is carried out in the dry condition because it allows the slider to condition in to the surface before the wet measurements are made.

3. RESULTS AND DISCUSSION

3.1. EFFECT OF SLIDER PREPARATION UPON THE VERIFICATION MEASUREMENTS

3.1.1. Slider preparation of 20 swings on P400 and 20 swings on wet pink lapping film

The mean PTVs from measurements of the verification surfaces were plotted against the number of times the slider had been re-prepared with 20 pendulum swings across the P400 grade abrasive paper and 20 swings across the pink lapping film, and are displayed in Figure 3.1.

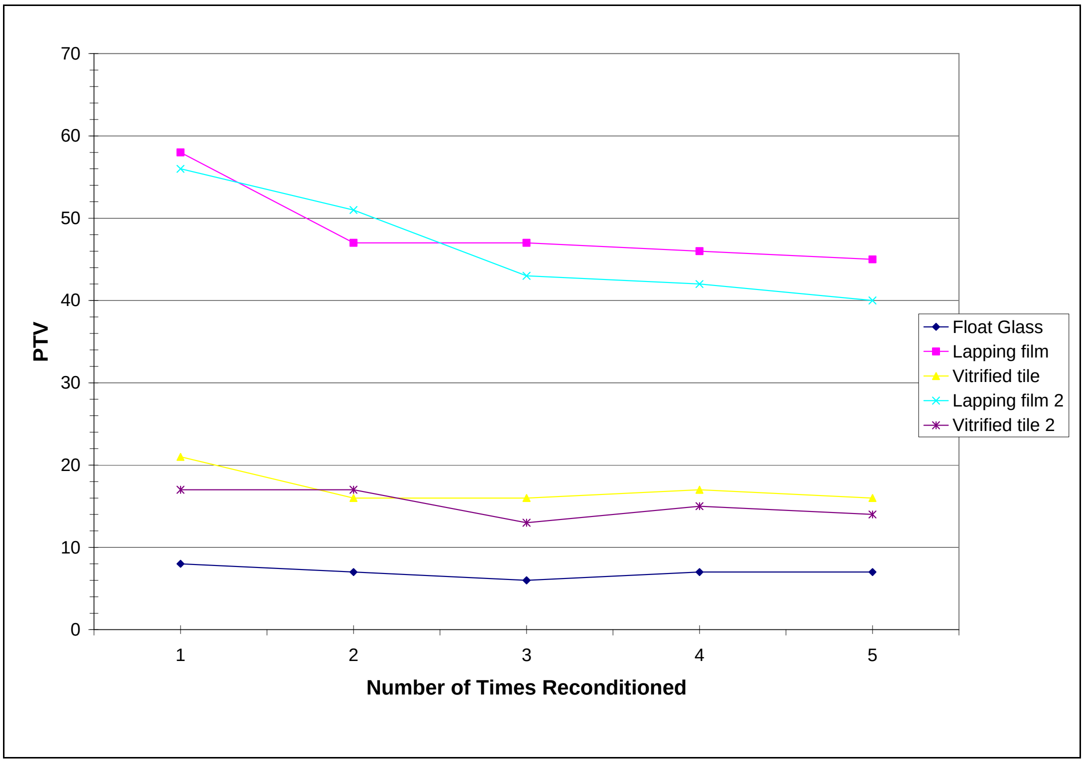

Figure 3.1. The mean PTV measured on the float glass, lapping film (PLF), and the vitrified ceramic tile verification surfaces. Measurements were made after the slider had been re-prepared with 20 pendulum swings on the P400 grade abrasive paper and 20 swings on the water-wet lapping film

The results displayed in Figure 3.1 show that on the float glass surface the PTVs obtained with the Slider 55 rubber only vary by a value of two after the working edge has been re-prepared up to 5 times. This suggests that the repeated conditionings of the slider and, therefore, larger working edge, has very little effect on the fluid film that is formed between the slider and surface. This may be due to the very low surface roughness of the float glass surface. It indicates that the float glass presents a very consistent verification surface for the Slider 55 rubber.

The results upon the vitrified ceramic tile show some reduction in the PTV across the five sets of measurements. The results suggest that the measured PTV on this surface becomes stable after two full conditionings of the slider, which suggests that the slider edge has to have a minimum length of approximately 2mm to produce a consistent verification PTV on this surface.

The PTV for the lapping film was 58 after the initial conditioning, and 40 after the fifth. This large fall in the measured PTV was probably due to the increasing length of the working edge of the slider (Hallas, 2008). This has the effect of increasing the thickness of the fluid film between the slider and surface, which in turn reduces contact between the slider and lapping film. The results show a similar trend to the PTVs on the vitrified ceramic surface. The verification measurement after two full conditionings can be significantly higher than subsequent measurements.

3.1.2. Slider preparation of 3 swings on P400 and 20 swings on wet lapping film

The mean PTV from measurements of the verification surfaces, described in 2.1, were plotted against the number of times the slider had been re-prepared with 3 pendulum swings across the P400 grade abrasive paper and 20 swings across the lapping film, and are displayed in Figure 3.2.

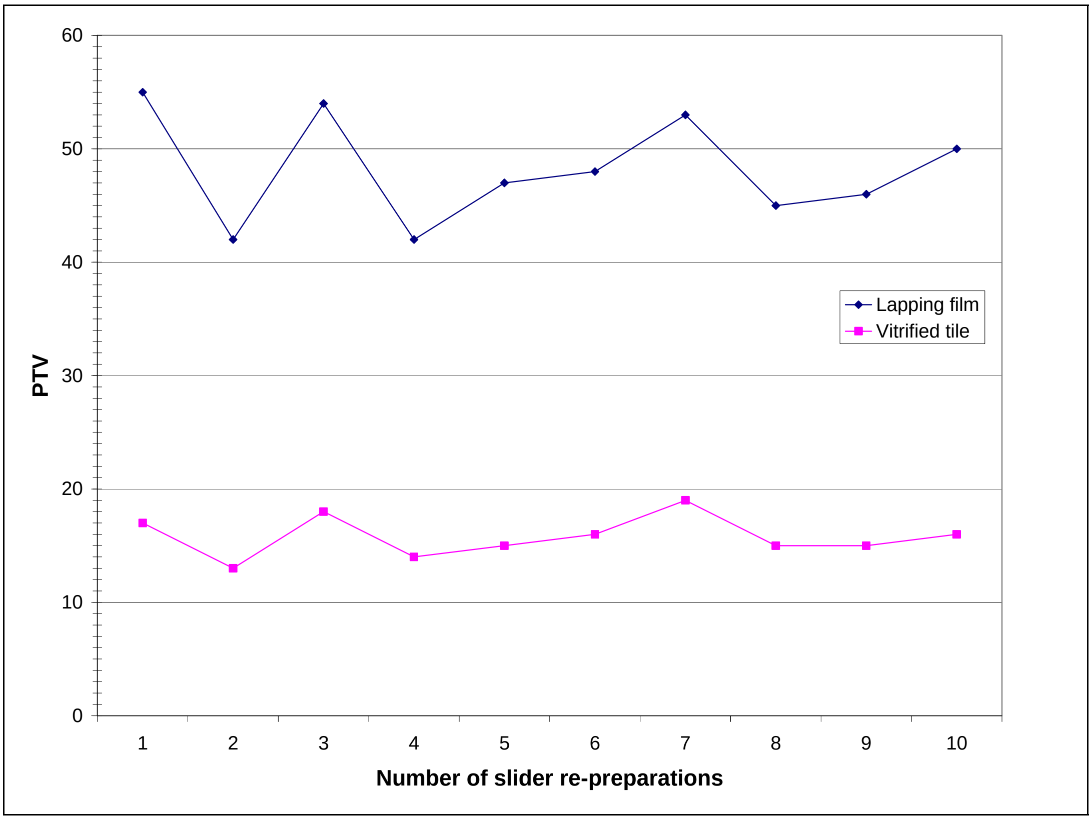

Figure 3.2. The mean PTV measured on lapping film (PLF) and the vitrified ceramic tile verification surfaces. Measurements were made after the slider had been re-prepared with 3 pendulum swings on the P400 grade abrasive paper and 20 swings on the water-wet lapping film

Re-preparing slider 55 rubber by carrying out 3 conditioning swings on the silicon carbide P400 grade abrasive paper and 20 swings on the lapping film surface, as the results displayed in Figure 3.2 show, leads to variation in the PTV. The verification measurements on the vitrified ceramic tile vary from a PTV of 19 to 13. The verification PTV on the lapping film shows a large range of values from 55 to 42. This suggests that this procedure leads to inconsistent removal of debris from the slider working edge, which affects the PTV, or the procedure does not produce a working edge long enough to result in a consistent PTV.

Conditioning the slider working edge with 20 swings on the P400 silicon carbide abrasive paper followed by 20 swings over the wet PLF, results in less variation in the verification PTV on both the Pink Lapping Film and vitrified ceramic tile surfaces. Full reconditioning of the slider, or a minimum slider working edge dimension for Slider 55 rubber, was applied to the measurements of the slip resistance of the floor surfaces with the pendulum test throughout this study.

3.2. SLIP RESISTANCE MEASUREMENTS

Figure 3.3 displays the Ramp Test results plotted for each operator, on each surface under the water contaminated, barefoot condition.

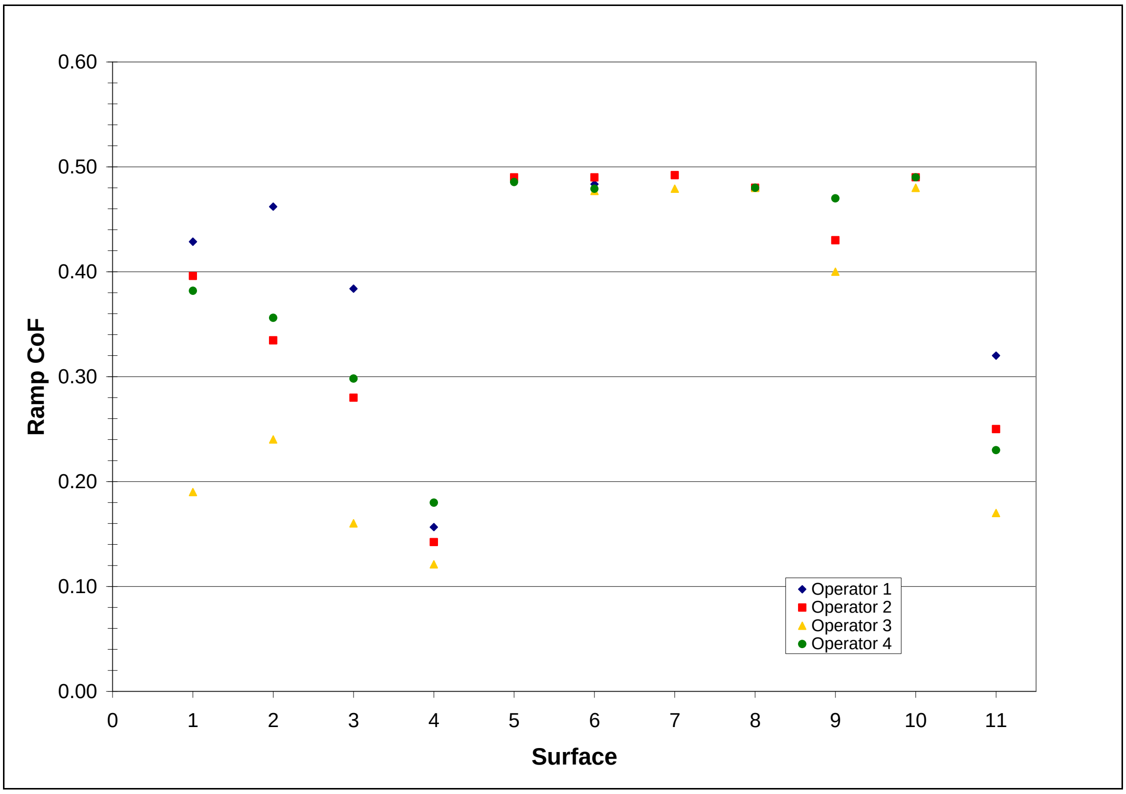

Figure 3.3. Ramp test results under the barefoot condition for each operator, on each of the eleven floor surfaces

The first three surfaces shown in figure 3.3 are smooth, ceramic surfaces. They present a wide range of slip resistance between the four operators, for example operator 1 records a ramp CoF of 0.43 and operator 3 records a CoF of 0.19 on surface 1. This large range in the barefoot slip resistance could be due to slight differences in the walking technique between individual operators, or differences in their skin friction, when assessing these surfaces under the water-contaminated condition. Differences in the gait adopted on the ramp test, such as step length, the placement of the foot or walking pace, which are not significant for the slip resistance when tested under the shod condition, may be much more critical when testing barefoot. Very little is known about friction requirements under the barefoot condition, or the variability of the skin in terms of slip resistance. The characteristics of an individual operator in terms of the properties of the skin, such as hydration or elasticity, may be dependent on age, and may have a significant affect on the slip resistance requirements of the individual. The sole of the foot cannot be prepared before a test to present a standardised surface in the same way as footwear and, as such, may lead to greater variation between operators in the measured slip resistance.

A number of different models for the friction between an elastomer and floor surface are discussed within current literature (Grönqvist, 1999, Leclercq, 1995). The total friction generated includes contributions from an adhesive component, which is the continuous formation and breaking of molecular bonds between the elastomer and the surface, where the liquid contaminant has been completely expelled, and a deformation or hysteresis component, which is produced by the stretching and relaxing of the elastomeric material as it passes over the surface asperities. (Hysteretic friction is the dissipation of energy within the bulk of a material, in this case the sole of the foot, as it is deformed and released.) The two components can be applied to the interaction between the barefoot and floor surface.

The smooth, ceramic surfaces (1, 2, and 3) shown in Figure 3.4, were laid with tiles positioned as close together as possible without spacers or grout. It is thought that the joints between the tiles contributed to the differences between the results of the four operators. Although the spacing between tiles was kept to a minimum, it is thought that the fluid film generated between the sole of the foot and the tile may break down towards the edges of the tile, reducing the slip distance and severity of any slip, leading to an affect referred to as “stick-slip”. The foot slips only a short distance, allowing the operator to regain balance.

It is also thought that the sole of the foot, particularly the forepart, under the barefoot condition, is much more sensitive to the joint lines between the tiles, causing greater interaction with the edges of the tile surface. This would increase the deformation component of the slip resistance generated. This effect seemed inconsistent between each walk carried out, and between each operator, which in turn led to different interpretations of a slip by the different operators. This is supported by the results generated on the fourth surface, the acrylic sheet (4 in Figure 3.4).

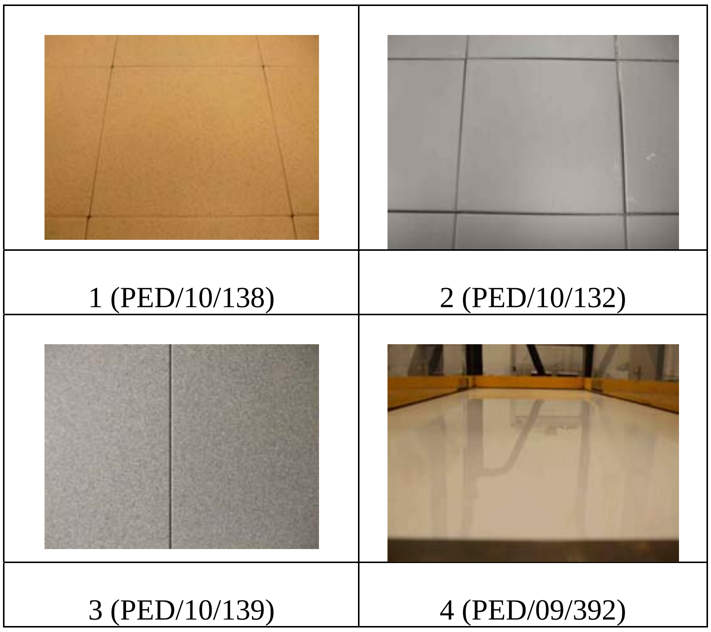

Figure 3.4.The four rigid surfaces used in the barefoot ramp tests, showing the three smooth, ceramic tiles and the acrylic sheet.

The closest agreement between the results of the four operators on the smooth surfaces was seen on the acrylic surface. This was most likely due to the very low surface roughness and, most significantly, because it was a large, single sheet surface, that is, there were no joints in the surface as seen with the ceramic tile surfaces, therefore, when a slip began, the fluid film was maintained, resulting in the continuation of the slip until balance was lost. The acrylic presented the lowest CoF of all the surfaces tested, as would be expected.

Figure 3.5 shows a comparison of the pendulum test results with Slider 55 rubber and the lowest results generated on the smooth, rigid surfaces (1 to 4) according to the ramp test, under the water-contaminated condition.

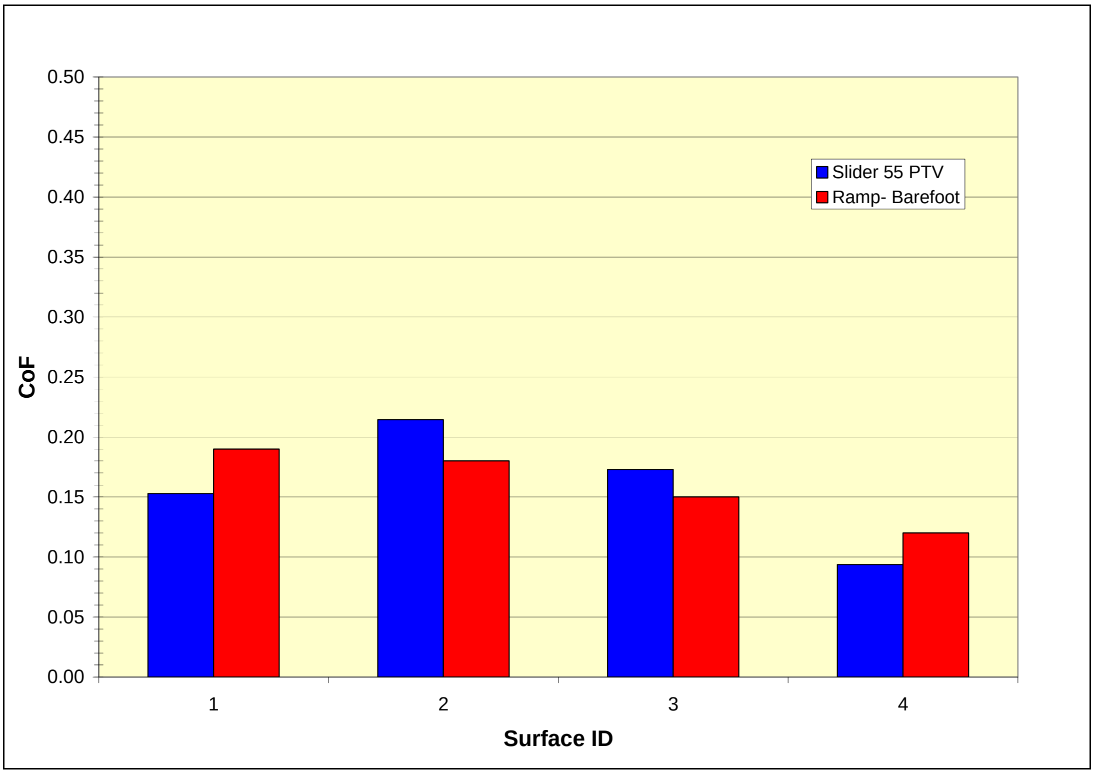

Figure 3.5. Comparison of the pendulum Test results with Slider 55 rubber and the lowest measurement of the CoF according to the HSL ramp test, under the water contaminated, barefoot condition on the rigid, smooth floor surfaces

The results in Figure 3.5 indicate that the PTVs measured with Slider 55 rubber under the water-contaminated condition agree closely with the lowest measurement of the CoF according to the HSL ramp test under the water-contaminated, barefoot condition. These results suggest that the pendulum measurement of slip resistance is representative of the lowest or worst case measurement of the slip resistance according to the ramp test. The contact distance of the pendulum is such that the slider does not cross the edges of the tile, therefore it is measuring the friction of the tile surface. The action of the pendulum means the slider cannot replicate the deformation of the foot that contributes to the hysteretic component of available friction when tested according to the ramp method. The range of results between operators on these surfaces suggest, in some cases, a significant contribution to the slip resistance of a floor surface under the barefoot condition is from the tactile interaction of the sole of the foot with the tile joints or macroscopic surface features.

The profiled, ceramic tile surfaces 5, 6 and 7, showing the different profile elements, are presented in Figure 3.6.

	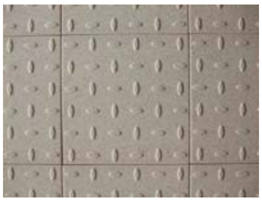	
5 (PED/10/135)	6 (PED/10/136)	7 (PED/10/134)

Figure 3.6. The profiled, ceramic surfaces

Table 2 shows the slip resistance measured on the profiled ceramic and vinyl surfaces according to both the pendulum test with Slider 55 rubber and the ramp test.

Table 2. A comparison of the pendulum test results with Slider 55 rubber and the lowest results generated on the profiled, ceramic surfaces and the vinyl surfaces according to the ramp test under the water contaminated condition

		Pendulum Test Results	***Barefoot Ramp***	
Surface I.D.	***R_z (μm)***	***CoF Dir 1***	***Critical Angle***	***CoF***
5 (PED/10/135)	8.34	0.29	26.0	>0.47
6 (PED/10/136)	34.0	0.46	25.8	>0.47
7 (PED/10/134)	31.12	0.50	25.9	>0.47
8 (PED/08/303)	13.53	0.34	25.6	>0.47
9 (PED/10/153)	21.08	0.41	21.8	0.40
10 (PED/10/154)	14.66	0.36	25.9	>0.47
11 (PED/06/282)	13.56	0.30	9.6	0.17

The ramp test results on surfaces 5, 6 and 7 when in the ex-factory condition, suggest that the profile elements can make a significant contribution towards the measured slip resistance. It should be noted that testing was stopped when the ramp acceptance angle was greater than 25°, so it may have been possible to measure a higher CoF.

The results measured with the pendulum on surfaces 6 and 7 indicate significant levels of slip resistance, which reflect the results generated with the ramp. The pendulum underestimates the available friction on surface 5 compared to the ramp. Surface 5 has flatter profile elements, with a larger surface area by comparison to surfaces 6 and 7. There is also a significant difference in the surface roughness of surfaces 6 and 7, which may be above a 30μm R_z surface roughness threshold that the pendulum Slider 55 rubber is sensitive to.

The vinyl surfaces used in this study are illustrated in Figure 3.7. Surfaces 8 and 10 have a studded profile surface, surface 9 has an integrated cork texture and surface 11 is a relatively smooth surface.

	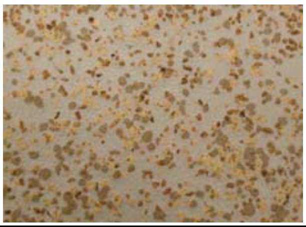
8 (PED/08/303)	9 (PED/10/153)
	
10 (PED/10/154)	11 (PED/06/282)

Figure 3.7. The vinyl surfaces without a profile, a studded profile or an integrated cork texture, and a rubber studded surface

The Slider 55 pendulum test results in Table 2, on the profiled, vinyl surfaces (8 and 10), indicate lower levels of slip resistance than results on the same surfaces measured with the ramp test under the barefoot condition. These results support the conclusion that the slip resistance measured according to the ramp test under the water-contaminated, barefoot condition is influenced significantly by profile elements or macroscopic texture of the surface, which opposes the horizontal force acting parallel to the slip direction. This increases the contribution of the deformation or hysteretic components to the available friction. It should be noted that all of the profiled surfaces were tested in the new, as-supplied condition, and the contribution of the profile elements or texture to the slip resistance is likely to change with wear, as definition of the profile is likely to be reduced.

The pendulum results for surface 9 agree closely with the lowest measurement of the slip resistance measured according to the ramp test.

The results on the smooth, vinyl surface (surface 11) indicate that the Slider 55 PTV presents higher measurements of slip resistance than the lowest ramp test result.

Overall, comparison of the slip resistance results measured using the pendulum test with Slider 55 rubber under the water-contaminated condition, with measurements made using the ramp test under the water-contaminated, barefoot condition, suggest that the pendulum is presenting a worst case measurement of the slip resistance. This is particularly true for the smooth, rigid surfaces used in this study. The contact area over which the pendulum measures the slip resistance is usually across the surface of a tile, whereas, on the ramp test, the tactile interaction of the foot with the joints between the tiles increases the deformation component of the available friction.

The results for the pendulum were closer to those of the ramp test on surfaces with a profile or macroscopic surface texture, but again presented a measurement of slip resistance that was generally lower than the ramp test. On the ramp test, the higher load generated by the operator leads to increased deformation (of the foot) over the profile elements or macroscopic texture of the test surface, resulting in a greater resistance to slipping. The structure of the foot, particularly the forepart region, is also likely to contribute towards this interaction. The impact action of the pendulum cannot replicate this interaction with such a surface, resulting in a lower measurement of the slip resistance.

Recent studies suggest the use of other materials, such as silicone rubber, may offer a more suitable alternative to Slider 55 rubber, that is more representative of the behaviour of the sole of the foot in the measurement of slip resistance (Medoff, 2010). None have suggested a simulant that can be re-prepared. Further studies of the suitability of other such materials for the measurement of slip resistance under the barefoot condition are necessary.

The evaluation of the slider 55 with the pendulum, for the measurement of the slip resistance of floor surfaces subject to barefoot, pedestrian traffic is purely based on a comparison of the slip resistance measurements with those of a human subject based reference test method. No evaluation of the material properties of the rubber, such as hardness or resilience with respect to the sole of the barefoot, has been made.

4. CONCLUSIONS

An investigation of the effect of the pendulum slider preparation method for Slider 55 rubber showed that reconditioning the Slider 55 working edge with 20 swings across the P400 silicon carbide abrasive paper, followed by 20 swings across the wet PLF results in a more consistent working edge to the pendulum slider, and thus repeatable measurement of the PTV with Slider 55 rubber. Results on the vitrified ceramic tile and PLF verification surfaces suggest that the PTV is more consistent after the second reconditioning.

Measurements of the slip resistance of floor surfaces used in this study according to the HSL ramp test method under the water-contaminated, barefoot condition, suggest that a significant component of the slip resistance is due to the deformation contribution from the tactile interaction of the sole of the foot with the profile elements or macroscopic texture of the surface.

The measurements of slip resistance according to the ramp test method has indicated that the friction requirements between operators can differ significantly under water-contaminated, barefoot conditions. Slip resistance measurements made with Slider 55 rubber according to the pendulum test in this study, have presented measurements, which agree closest with the lowest or worst case measurement of slip resistance according to the ramp test.

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6. APPENDICES

Appendix A

The HSL Ramp Test

HSL currently prefers a subject-based technique to replicate the conditions that lead to a slip. The HSL Ramp Test can be used to assess the slip resistance of different floor surfaces (using standard footwear or with operators in the barefoot condition), or different examples of footwear (using standard floor surfaces). The test method is similar to RAPRA's CH001 and CH002 test methods, and the established German standards for the assessment of floor surfaces, namely DIN 51130: 2004 and DIN 51097:1992.

The ramp, pictured in Figure A.1, consists of an adjustable platform (2), upon which the floor surface to be tested is positioned. A safety rig (1) with a fall arrest facility (3) is located over the platform to prevent injury to the operator during a test. Water is applied to the test surface at a flow rate of approximately 6 litres per minute. Other contaminants can also be used with the ramp to replicate specific workplace conditions, including glycerol, motor oil, and sodium lauryl sulphate solution.

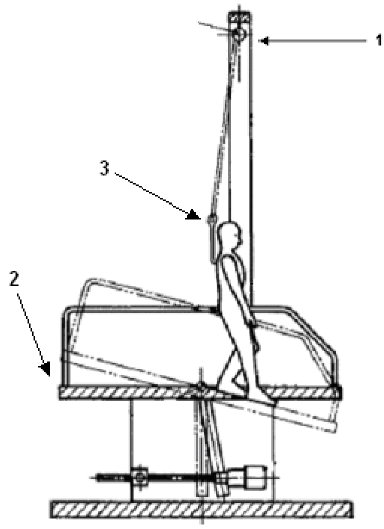

Figure A.1. The HSL Ramp Test. (Diagram adapted from DIN 51130)

A test requires the trained operator to carry out a series of controlled walks over the floor surface under study. The walking method involves the operator taking a series of half steps forward then backward, returning to their start position. This is repeated in a continuous movement. The walking speed is controlled at approximately 144 steps per minute using a metronome. If the operator completes the walk without a slip or any interference to their gait occurring, the angle of inclination of the ramp platform is increased by approximately 1°, and then the operator repeats the whole procedure.

This process is continued until an inclination is reached where a slip occurs, or the operator can no longer maintain the required gait. This inclination is known as the acceptance angle. The acceptance angle is recorded from a display, which is hidden from the operator. The ramp platform is returned to an angle of inclination below the acceptance angle and the process is repeated. This continues until twelve values for the acceptance angle have been generated. The highest and lowest angles are disregarded, and a mean acceptance angle (known as the critical angle) is calculated from the remaining ten values. The critical angle of a second operator is generated in the same way. When testing footwear or floor surfaces under the shod condition, the critical angle of each operator is required to agree within a tolerance of 2°. If the results do not agree, a third operator is required to generate a mean acceptance angle.

The mean critical angle of the two operators is related to the coefficient of friction by the tangent of the angle.

Appendix B

Adapted from:

'The Assessment of Floor Slip Resistance:

***The UK Slip Resistance Group Guidelines*', Issue 3, 2005.**

Note: The information presented below is intended as a guide. Other factors, such as level and type of pedestrian activity and user demographic (such as age and physical ability) should be considered. A risk assessment should be conducted in all situations.

Rz Surface Roughness (μm)	**Slip Potential**
0 - 10 μm	High
10 - 20 μm	Moderate
>20 μm	Low

Pendulum Test Value	**CoF**	**Slip Potential**
0 – 24	0 – 0.24	High
25 – 35	0.25 – 0.36	Moderate
> 35	> 0.36	Low

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Suitability of Slider 55 rubber for use as a standardised slider material for the simulation of barefoot pedestrians

Slider 55 rubber has been used by the United Kingdom Slip Resistance Group (UKSRG) with the Pendulum Test to simulate the slip resistance characteristics of a barefoot pedestrian, when assessing floor surfaces for use in shower areas, changing rooms and swimming pools. The aim of this study was to investigate the suitability of Slider 55 rubber for this purpose.

A market survey was carried out, in order to source a representative range of surfaces typically used under water-contaminated, barefoot conditions. Surfaces were selected that would potentially present a range of slip resistance when under test. This included both ceramic and vinyl surfaces, which were both profiled and non-profiled. The slip resistance of each of the floor surfaces was assessed according to the HSL Ramp Test, using four operators.

Before pendulum measurements were carried out on the test surfaces, the effect of the pendulum slider preparation procedure on the pendulum test values measured was investigated. Three verification surfaces were used in this investigation; float glass, vitrified ceramic and Pink Lapping Film (PLF).

To assess the applicability of the pendulum test method with the Slider 55 rubber, to water-contaminated, barefoot conditions, the pendulum test measurements were compared with slip resistance measurements made with the HSL ramp test.

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