Health and Safety Executive

A study of the effect of modifying the European Standard mechanical slip resistance test for footwear

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Research Report

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A study of the effect of modifying the European Standard mechanical slip resistance test for footwear

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Employers use a range of control measures to reduce the risk of slips injuries, but if a significant slip risk remains, introducing footwear with slip-resistant properties may be necessary.

The Health and Safety Laboratory (HSL) uses a human-based ramp test to assess the slip resistance of footwear. The human-based principle ensures that the parameters of a slip are closely replicated, therefore establishing confidence in the results generated. The current European Standard for footwear slip resistance is a mechanical friction test that attempts to replicate the action of a slipping foot. However, the slip resistances given by this test do not always agree with those given by the HSL ramp test for the same footwear.

This work studied the effects of modifying two parameters of the mechanical test, in order to establish closer agreement with the HSL Ramp Test. By improving this agreement, the mechanical test could be developed as a convenient alternative to the ramp test for HSL assessments of the slip resistance of footwear, both in research and slips investigations.

Modification of two parameters (slip velocity and vertical force) controlling the mechanical test in the heel slip mode resulted in improved agreement between the two tests for the limited number of samples tested. Further confirmation of the effect of optimising these parameters is necessary. Modification of further mechanical test parameters is also necessary, since the modified mechanical test currently underestimates the available slip resistance compared to the ramp test.

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EXECUTIVE SUMMARY

Objectives

The Health & Safety Laboratory (HSL) currently uses a pendulum test for assessing the slip resistance of floor surfaces and a human-based ramp test to assess the slip resistance of footwear and floor surfaces. This human-based test involves an operator carrying out a series of closely controlled walks across an inclined test surface, until an inclination is reached at which a slip occurs. The human-based element of the test ensures that the parameters of a slip are closely replicated, therefore establishing confidence in the results generated. Footwear that the HSL Ramp Test has identified as having good slip resistance under certain test conditions has subsequently performed well in workplace trials. Similarly, footwear that has performed poorly in a workplace environment has subsequently shown poor slip resistance when tested according to the HSL Ramp Test method.

The current European and International Standard for the measurement of the slip resistance of footwear is EN ISO 13287:2007 Personal Protective Equipment – Test Method for Slip Resistance. This is a mechanical test that attempts to replicate the action of a slipping shoe. However the slip resistances given by this test do not always agree with those given by the HSL ramp test for the same footwear. It is believed that this is, at least partly, because the parameters of the current Standard test method do not allow the recreation of the fluid film that forms during a slip, particularly when a common, less viscous contaminant, such as water, is tested upon surfaces of low surface roughness, such as steel.

The main objective of the work was to study the effect of modifying the parameters of the mechanical test method, in order to establish closer agreement between the results generated by the mechanical friction test and the HSL Ramp Test. By improving the agreement between the two test methods, the mechanical friction test could be developed as an alternative test method to the ramp test for assessing the slip resistance of footwear and floor surfaces, both in research and slip investigation work.

Main Findings

Modification of two of the parameters (slip velocity and vertical force) controlling the mechanical friction test resulted in improved agreement between the results generated by the HSL Ramp Test and those generated with the mechanical friction test in the heel slip mode, for the limited number of samples of footwear tested.

The modified test method tends to underestimate the slip resistance of footwear, when compared to the HSL Ramp Test method under some test conditions.

Recommendations

This study has laid the foundations for further work. With a laboratory assessment, it has begun to address the issue of the disagreement between mechanical friction test and ramp test data. However, further modification of the test parameters of the mechanical friction test is necessary, since the modified test method currently underestimates the available slip resistance.

Further confirmation of the effect of optimising the parameters of the mechanical friction test method is necessary. This could be achieved by testing a larger range of occupational footwear to the modified parameters, under different test conditions.

Investigation of the other footwear test modes (forepart and flat) could be carried out to establish whether the relationship between the results generated according to the modified parameters of the mechanical friction test and the HSL Ramp Test also exists for these other modes.

1 INTRODUCTION

The measurement of slip resistance of flooring and footwear has always been the subject of much debate with respect to the validity of the data that the test methods involved present. Many tests claim to operate according to the parameters derived through biomechanical measurements made through studies of walking or slipping in the laboratory, yet agreement between the results such tests generate, in terms of the Coefficient of Friction (CoF), seems to be poor at best.

The Health and Safety Laboratory (HSL) currently favours two test methods for assessing slip resistance, the pendulum test for assessing the slip resistance of floor surfaces and the ramp test for assessing the slip resistance of both occupational footwear and floor surfaces. Ramp tests replicate the conditions of a slip, using a human subject to actually generate the CoF, therefore replicating the parameters, such as the forces and contact time, very closely. Confidence in the results that the HSL Ramp Test method generates has been established over time through extensive testing of occupational footwear, in which the Ramp Test has successfully identified footwear with good slip resistance properties. This has been supported by workplace trials, where such footwear made a significant contribution towards a reduction in the incidence of slip accidents (Thorpe et al, 2002). Likewise, footwear that has performed poorly in a workplace environment has similarly been shown to have poor slip resistance properties when subsequently tested using the HSL Ramp Test.

The current International and European Standard test method for the measurement of the slip resistance of footwear, EN ISO 13287: 2007, is a mechanical test, which measures the CoF by attempting to recreate the action of a slipping shoe. The test conditions and slip resistance requirements according to this test, with regard to safety, protective and occupational footwear, are defined within the 2007 amendments to the series of Standards relating to personal protective equipment, EN ISO 20344:2004, EN ISO 20345:2004, EN ISO 20346:2004, and EN ISO 20347:2004.

The Health and Safety Executive (HSE) and HSL have for some time had concerns over the test pass thresholds within these Standards and how they compare to pedestrian friction requirements in maintaining a normal gait. HSL also have reservations about whether the test recreates the dynamics of fluid film formation during a slip closely enough, particularly when operated with test conditions including water-based contaminants.

The test is controlled by a number of parameters which have been identified from biomechanical studies as critical with regard to accurately recreating slip conditions during walking (Perkins, 1978). Hydrodynamic lubrication theory estimates the effect that altering the parameters, such as the vertical load and the slip velocity, has upon the fluid film formation, and thus, the measured CoF. It is thought that modifying the test parameters of the mechanical friction test will alter the dynamics of the fluid film between the footwear and floor surface, thus influencing the resulting CoF measurement.

This report describes work to study the effect of modifying the test parameters of the mechanical friction test on the measured CoF, with a view to developing a test method which shows closer agreement with the HSL Ramp Test under the same test conditions. Initial results of tests to evaluate the new test parameters are also reported.

2 BACKGROUND

2.1 THE STM 603 SLIP RESISTANCE TESTER

Figure 1. The STM 603 Slip Resistance Tester

The STM 603 Slip Resistance Tester is a computer-controlled friction test, designed to measure the slip resistance performance of footwear. Alternatively, the slip resistance of floor surfaces can be assessed with standard soling materials as test pieces. The test can operate to the current European and International Standard EN ISO 13287:2007 Personal Protective Equipment – Footwear – Test Method for Slip Resistance, which is based on a test method defined by the manufacturer of the test equipment. It can also operate to a user defined test method, within the limitations of the machine. Similar slip testing machines, which operate in accordance with EN ISO 13287:2007, are also used to measure slip resistance of footwear to this Standard.

The footwear is fitted onto a shoemaking last and attached to the cage plate of the friction rig, as pictured to the right hand-side of Figure 1. A test floor surface is located upon the carriage beneath the footwear. When the test operates, a pneumatic cylinder lowers the cage plate, and thus the footwear, onto the floor surface below and applies the required vertical force to it. After a short, static delay time, a variable speed motor draws the carriage and floor surface beneath the footwear. Two transducers measure the horizontal force developed between the footwear and floor surface, and the ratio of the horizontal and vertical forces is displayed as the CoF on the computer screen. Each CoF measurement is also displayed in graphical form (Figure 2), which also illustrates some of the test parameters during the test. The software allows a maximum of ten measurements of the CoF to be made within a single series of tests, from which the CoF is taken as a mean from the last 5 measurements.

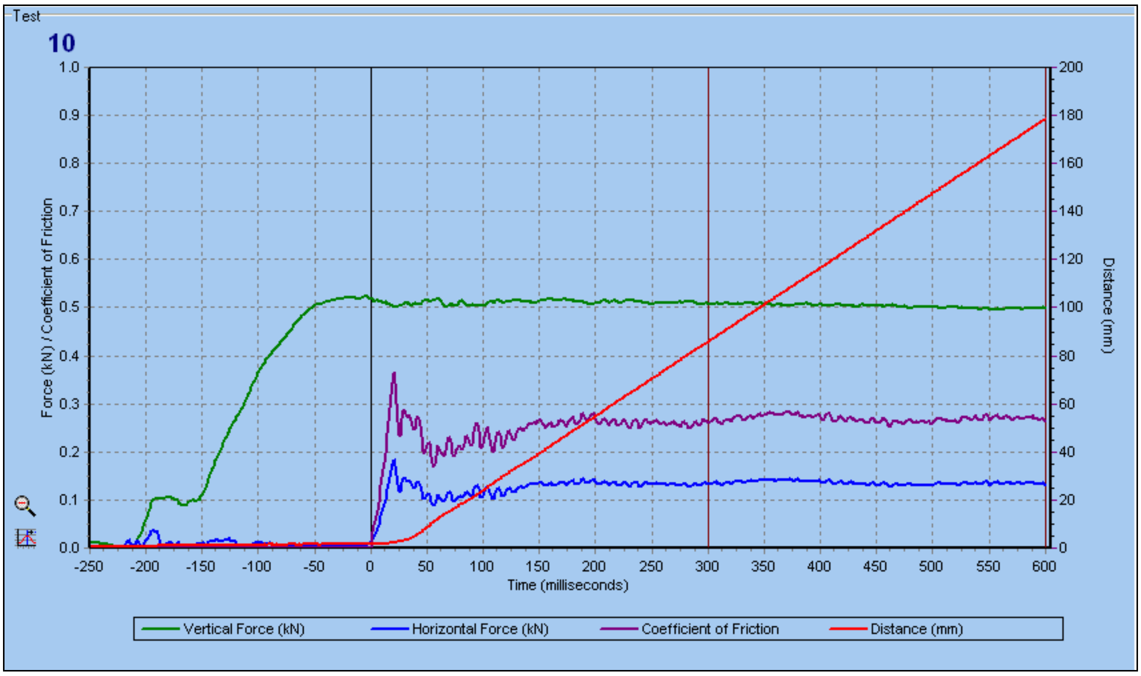

Figure 2. Typical graph illustrating a CoF measurement as displayed by the STM 603 Slip Resistance Tester

The software allows the test parameters to be controlled within the limits of the machinery. The test parameters include the:

Vertical Force - the vertical force applied to the footwear, perpendicular to the test surface. In EN ISO 13287:2007, this has a value of 500±25N for footwear sizes of 40 Paris points and above, or 400±20N for footwear sizes below 40 Paris points. In Figure 2, the green line represents the vertical force.

Slip Speed – the speed at which the floor surface is drawn along under the footwear. In EN ISO 13287:2007, the slip speed is set at 0.3±0.03ms^{-1}.

Snapshot Low – the snapshot defines the time interval over which the measurement of the horizontal force is made. Snapshot low is the time that the measurement begins. It is illustrated in Figure 2 by the vertical line at 300ms. In EN ISO 13287:2007, snapshot low is defined as 0.30s.

Snapshot High – the time at which the measurement of the horizontal force ends. It is illustrated in Figure 2 by the vertical line at 600ms. In EN ISO 13287:2007, snapshot high is defined as 0.60s.

Static Contact Time – the time interval between the footwear initially making contact with the test surface and the start of the movement of the test surface. EN ISO 13287:2007 defines a maximum static contact time of 1.0s, but the machine used in this study was thought to have this parameter defined in the software as 0.5s.

Slip Distance – the distance for which the footwear is in contact with the test surface. This is not defined in the standard test method. Again, the software was thought to have the slip distance defined as 0.2m, under EN ISO 13287 test.

Average Over – the number of measurements over which the mean CoF is made. For the purposes of this study, this always comprised the last five results from a full cycle of 10.

Three different test modes for footwear are possible, including the forward heel test (as shown in Figure 3), a backward forepart test, or a forward flat test, but tests can also be carried out upon samples of soling materials and heel top pieces. All measurements made throughout this study were made in the 7º forward, heel slip mode. Various combinations of footwear, floor surface and contaminant can be tested.

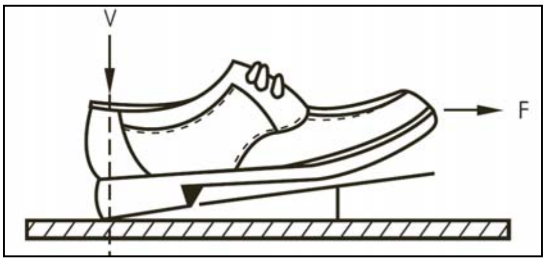

Figure 3. An illustration of the heel test mode. V indicates the direction of application of the vertical force. Diagram adapted from EN ISO 13287:2007

2.2 THE HSL RAMP TEST

The HSL ramp test is one of the two preferred methods of HSL for assessing slip resistance performance. The HSL Ramp Test can be used to assess the slip resistance of different examples of footwear (using standard floor surfaces) or different floor surfaces (using standard footwear).

The HSL-PS-SOP12 ramp test procedure is a human subject-based technique based upon the established German Standards for the assessment of floor surfaces, namely DIN 51130 and DIN 51097. The procedure closely replicates the conditions that lead to a slip.

The ramp, pictured in Figure 4, 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 via a series of crop sprays. Other contaminants can also be used with the ramp to replicate specific workplace conditions, including glycerol, motor oil, sodium lauryl sulphate, and dry contaminants.

The test requires the trained operator to carry out a series of controlled walks over the floor surface. 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 the operator's gait occurring, the operator then increases the angle of inclination of the ramp platform by approximately 1°, and then repeats the whole procedure.

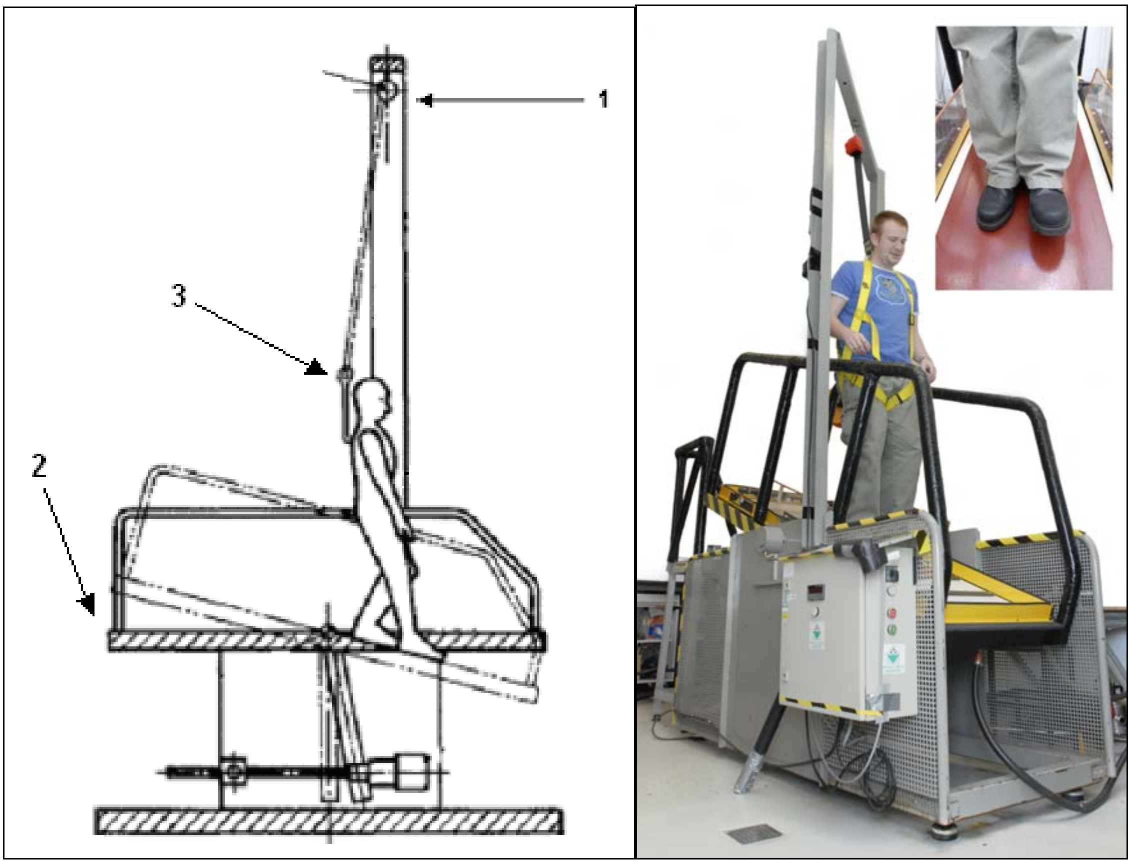

Figure 4. The HSL Ramp Test. Diagram adapted from DIN 51130

The whole process is repeated until an inclination is reached where a slip occurs; this inclination is known as the critical angle. The critical angle is recorded from a display, which is hidden from the operator. The ramp platform is returned to an angle of inclination a few degrees below the critical angle and the process is repeated. This continues until twelve values for the critical angle have been obtained, with the highest and lowest disregarded. A mean critical angle is calculated from the remaining ten values. The mean critical angle of a second operator is calculated in the same way and, if the mean critical angles of the two operators agree to within a tolerance of two degrees, the results are used to calculate the CoF. If the mean critical angles of both operators fail to agree within the required tolerance, a third operator will generate a third mean critical angle.

Slider 96-soled footwear is normally used as the standard footwear when the ramp test is being used to assess the slip resistance of floor surfaces. Footwear is prepared before each set of walks using a hand sander and P400 grit abrasive paper.

3 EXPERIMENTAL PROCEDURES: FOOTWEAR, CONTAMINANTS AND SURFACES

3.1 TEST MATERIALS AND FOOTWEAR

Since the task of modifying the parameters, one by one, in order to establish optimised settings involved numerous tests, a soling material was required which could be repeatedly reconditioned and used in further tests, without undergoing any detrimental change in performance that would affect subsequent results. The United Kingdom Slip Resistance Group (UKSRG) use a standard rubber compound to assess the slip resistance of floor surfaces, known as slider 96, which simulates a shoe soling material of moderate performance. Slider 96 has low resistance to abrasion and, therefore, can be reconditioned to provide a reproducible surface between tests. The most appropriate form of the slider 96 soling material was as a sheet attached as a smooth, flat sole to a bowling shoe. The smooth sole means that the CoF measured is not influenced by a cleating pattern. This is in the same form as used in HSL's SOP-12 ramp test method for the assessment of floor surface slip resistance.

For the final phase of the study, ten examples of industrial footwear were selected to evaluate the modified test parameters for the mechanical friction test. Footwear was selected which had been shown to have a range of slip resistance performance by the ramp test during a previous study of occupational footwear (Loo-Morrey, & Houlihan, 2007).

3.2 TEST SURFACES

Three different floor surfaces that would be expected to offer differing levels of slip resistance under similarly contaminated conditions were selected for the tests:

- a stainless steel surface, as defined in the Standard EN ISO 13287:2007, with a mean R_Z surface roughness of 1.6-2.5μm;
- a ceramic tile with a mean Rz surface roughness of 11.0-12.0μm
- a quarry tile surface with a mean R_Z surface roughness of 12.0-14.0μm.

The R_Z surface roughness of each surface was measured in accordance with the procedure described within EN ISO 13287:2007.

The steel surface and quarry tile surface were also chosen because they are standard surfaces for footwear testing using the ramp test.

During the parameter modification tests the surface roughness of the steel surface was measured at regular intervals, in order to confirm that it remained within the limits defined within EN ISO 13287:2007. The surface roughness measurements for the steel surface are included in Appendix A.

3.3 CONTAMINANTS

Water is one of the most common contaminants found in the workplace and is regularly used as a contaminant with the HSL Ramp Test. Potable water was therefore used as the main contaminant during the initial baseline CoF measurements, and as the contaminant for all of the parameter modification tests on the mechanical friction test. Glycerol, another standard contaminant used with the HSL Ramp Test, was a second contaminant in the validation tests, since it would allow a direct comparison of the results generated by the two tests.

4 EXPERIMENTAL PROCEDURES: INITIAL SLIDER 96 TESTS

4.1 METHOD

A series of tests were carried out according to the HSL SOP-12 Ramp Test method using slider-96 footwear. The footwear was prepared before each test using P400 grit abrasive paper. The CoF was measured on the steel, ceramic tile and quarry tile surfaces, with potable water as the contaminant.

Measurements of the CoF were then made using the mechanical friction test using the same slider 96 footwear used to generate the ramp data. The footwear was size 10 (44) and fitted upon a size 43 last. The footwear was prepared for each cycle of measurements in accordance with the procedure outlined within EN ISO 13287:2007. All measurements were made in the heel test mode, in which the footwear is set at a contact angle of 7° and undergoes a slip in the forward direction. The measurements were made according to the test method EN ISO 13287:2007 for 40 Paris points and above, defined in the software. The tests were made on the three test surfaces, with water contamination applied between each measurement by hand spray. The mean CoF value was calculated from the last 5 results from a series of 10 measurements.

4.2 RESULTS AND DISCUSSION

Table 1 shows the CoF measurements for the slider 96 footwear according to the two test methods.

Table 1. COF results for slider 96 footwear on the three water-wet test surfaces (red represents a high slip potential, amber a moderate slip potential and green a low slip potential)

Surface	HSL ramp test Mean CoF	Mechanical friction test (EN ISO 13287:2007 parameters, heel test mode) Mean CoF $_{6-10}$
Steel	0.03	0.27
Ceramic	0.18	0.24
Quarry	0.57	0.6

It is clear from Table 1 that the mechanical friction test overestimates the available friction upon the steel surface when the test is carried out according to the parameters outlined within EN ISO 13287:2007. However the results upon the quarry tile surface are close to those generated according to the ramp test.

On a surface of low surface roughness, such as the steel, the friction most likely results from adhesion between the shoe sole and the smooth steel surface. The presence of a contaminant such as water will reduce the contact area, and therefore the amount of adhesion taking place. The results in Table 1 suggest that in the mechanical test there is very little contaminant between the footwear and the steel, resulting in an overestimate of the available friction.

As surface roughness increases, the contribution to the measured CoF from adhesion reduces, and the contribution from deformation (or hysteretic) friction dominates. This is shown by the close agreement between the CoFs given by the two test methods for the quarry tile surface, which has much greater surface roughness than the steel, because of the greater surface roughness, the adhesive friction is less important and the fluid film between the shoe and surface has less effect on the measured CoF.

4.3 INITIAL CONCLUSIONS

The initial results suggest that the test, operated according to the test parameters of EN ISO 13287:2007, is failing to reproduce the correct fluid film dynamics under particular test conditions.

Modification of the test parameters, particularly the slip velocity and the vertical force, should improve the fluid film dynamics and result in CoF measurements which show closer agreement with the ramp test results.

5 EXPERIMENTAL PROCEDURES: MODIFICATION OF MECHANICAL FRICTION TEST PARAMETERS

5.1 METHOD

In order to develop closer agreement of friction test results with results generated according to the HSL Ramp Test, the effect of modifying the friction test parameters was investigated. Tests were carried out by altering one of the test parameters at a time. The tests were carried out upon the stainless steel surface, with water as the contaminant. The footwear used was the slider 96 footwear, and each test was carried out in the heel test mode. The footwear and test surface were prepared in accordance with the procedures outlined within EN ISO 13287:2007.

5.1.1 Slip Velocity

The slip speed is believed to have significant influence upon the formation of a fluid film between the footwear and floor surface, and thus, the measured CoF. The CoF was measured at slip speeds of $0.1ms^{-1}$, $0.2ms^{-1}$, $0.4ms^{-1}$ and $0.5ms^{-1}$, in order to observe the effect of changing the slip speed upon the CoF.

EN ISO 13287:2007 sets the snapshot low and high times at 300ms and 600ms respectively, and the slip distance is believed to be 0.20m. At a slip speed of $0.5ms^{-1}$ the footwear would have completed the slip distance after 0.4s, which is before the end of the snapshot interval. The slip distance could not be altered in such a way that the slip continued over a distance of 0.3m. Therefore, the snapshot interval was modified to times of 0.15 and 0.35 for the snapshot low and snapshot high times, respectively.

5.1.2 Vertical Force

The effect of the vertical force upon the CoF was investigated using the slip velocity derived from the tests described within 5.1.1. Measurements of the CoF were carried out at a slip velocity of $0.5ms^{-1}$ and an appropriate snapshot interval, as described previously. The CoF was measured at loads of 500N, 400N, 300N, 200N and 150N.

5.1.3 Static Contact Time

The static contact time is important because it may reduce the volume of contaminant between the footwear and floor surface during a measurement, particularly for less viscous contaminants such as water. Although attempts to measure the CoF at modified static contact times were made, the modified parameters affected the operation of the machine in such a way that measurement was not possible. The static contact time was therefore left at the time the standard test method uses, which is 0.5s.

5.2 RESULTS AND DISCUSSION

5.2.1 Slip Velocity

Figure 5 illustrates the variation of the mean CoF measurement as the slip velocity of the mechanical test is increased. At slip velocities up to $0.3ms^{-1}$, the mean CoF remains at a value of 0.27. At slip velocities greater than $0.3ms^{-1}$, the CoF starts to decrease, suggesting a change in the formation of the fluid film between the footwear and steel surface. The Standard defines a slip velocity of $0.3ms^{-1}$, but, for the slider 96 footwear and test conditions applied in this study, it seems that the slip velocity makes little or no difference to the CoF generated at or below $0.3ms^{-1}$. This suggests that little or no contaminant inhibits the adhesive contact between the footwear and floor surface at these low velocities. Tests at velocities above $0.5ms^{-1}$ were not possible due to the limitations of the machine. For the subsequent vertical force tests a slip velocity of $0.5ms^{-1}$ was used.

On the ramp, a combination of slider 96 footwear and water-wet steel leads to slips occurring at 2-3 degrees (a CoF of around 0.03). However, a threshold value of 0.09 was selected as an acceptable CoF for the mechanical friction test because 0.03 is too low for the test equipment used in the Standard to measure. The broken red line at 0.09 in Figure 5 corresponds to a ramp angle of approximately 5 degrees and represents the threshold used in our tests.

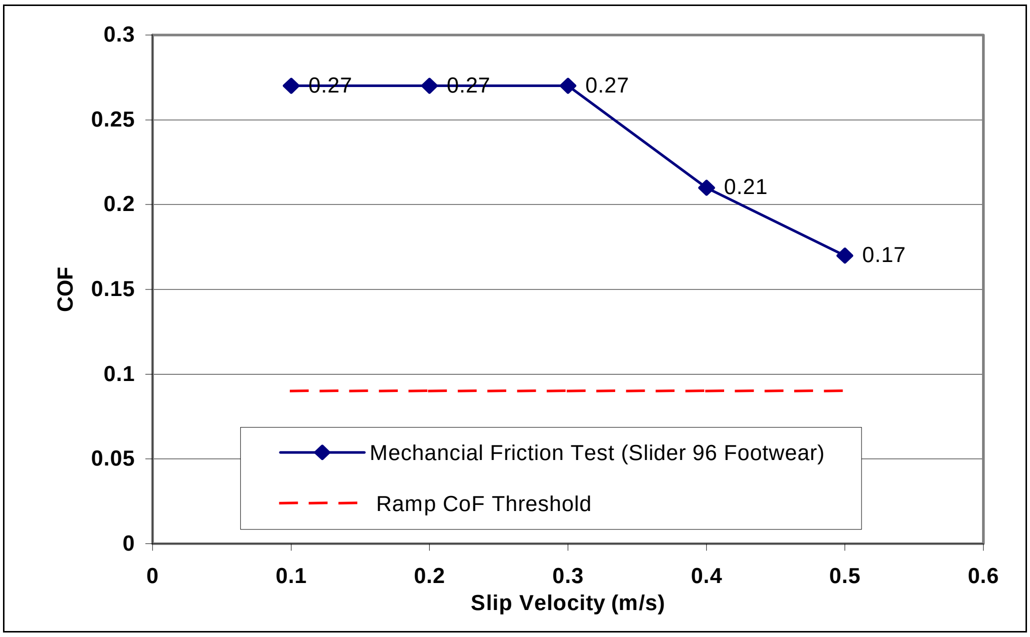

Figure 5. Variation in measured CoF with slip velocity (slider 96 footwear on wet steel)

5.2.2 Vertical Force

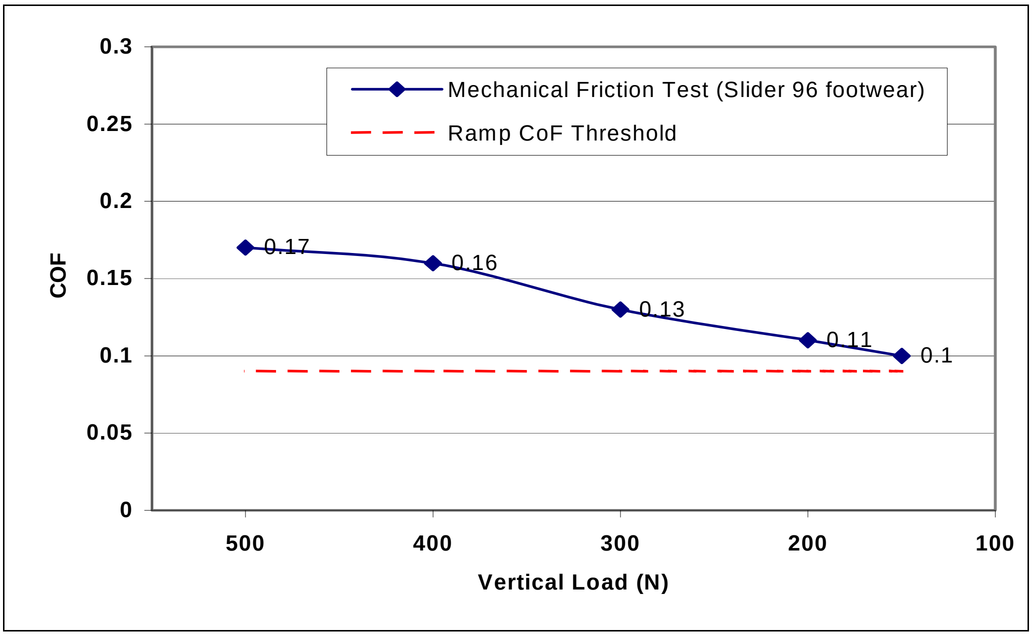

Figure 6. Effect of decreasing the vertical force upon measured CoF (slider 96 footwear on wet steel)

Figure 6 is a graph of the CoF, as measured using the mechanical friction test, against the decreasing vertical force. The measured CoF starts at a value of 0.17, when the vertical force is 500N. As the force is reduced to 150N, the CoF reaches a value of 0.10, close to the ramp CoF threshold. Tests at 100N did reduce the CoF further, but at these reduced loads the mechanical test became more unreliable. As the mechanical test showed closer agreement with the results generated with the ramp test for 150N than for 500N, a vertical force of 150N was adopted for the subsequent validation tests. However further investigation of the vertical force parameter is recommended.

5.2.3 CoFs using the modified parameters for all water-wet test surfaces

Table 2 and Figure 7 give the CoF results of the slider 96 footwear on all the test surfaces, when tested according to the modified test parameters. The HSL Ramp Test results and EN ISO 13287 are included for comparison.

Table 2. CoFs for slider 96 footwear according to three test methods (red represents a high slip potential, amber a moderate slip potential and green a low slip potential)

Surface	HSL ramp test	Mechanical friction test	
	Mean CoF	EN ISO 13287:2007 parameters Mean CoF $_{6\text{-}10}$	HSL modified parameters Mean CoF $_{6\text{-}10}$
Steel	0.03	0.27	0.1
Ceramic	0.18	0.24	0.25
Quarry	0.57	0.6	0.51

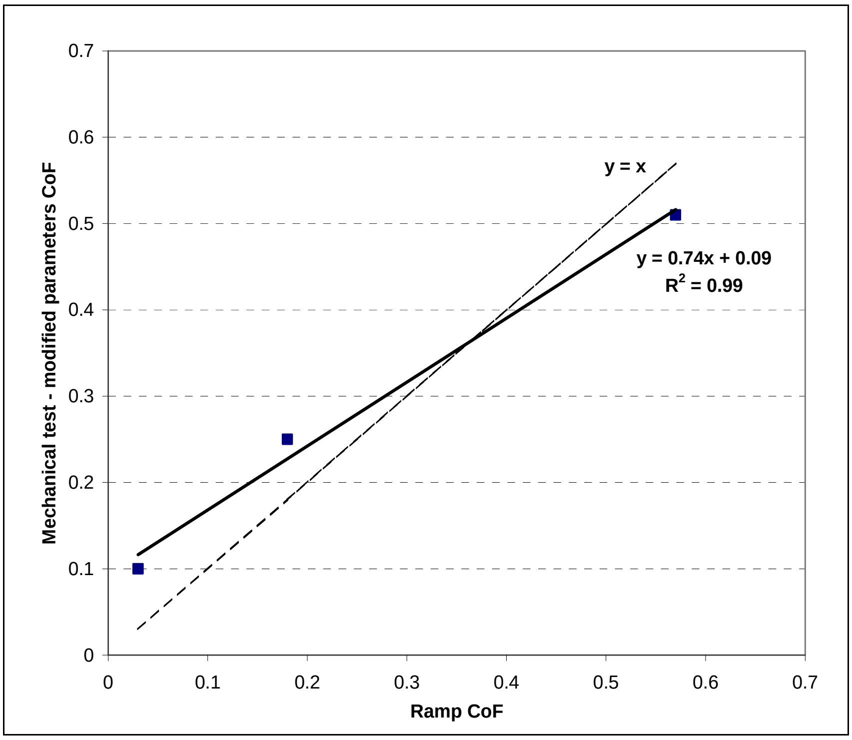

Figure 7. CoFs for slider 96 footwear – modified parameters

The CoFs obtained for slider 96 footwear on water-wet steel using the modified test parameters show closer agreement with the HSL ramp test results than those obtained using the EN ISO 13287:2007 test parameters. On water-wet ceramic and quarry tiles, the modified test gave similar results to the European test.

6 EXPERIMENTAL PROCEDURES: VALIDATION TESTS

6.1 METHOD

A selection of 10 examples of occupational footwear that had previously been tested according to the HSL Ramp Test method were tested using the STM 603 Slip Resistance Tester according to the modified test method. Measurements of the dynamic CoF were made according to the following test parameters:

Snapshot Low:	150ms
Snapshot High:	350ms
Vertical Force:	150N
Slip Speed:	$0.5ms^{-1}$
Static Contact Time:	0.5s
Slip Distance:	0.2m
Average Over:	5 Results
Initial contact load:	40N

The initial contact load was left at 40N, in order to reduce the possibility of the machine malfunctioning, as had previously been experienced with modifications to the static contact time.

Measurements of the CoF were made under the following test conditions: steel plate surface, contaminated with potable water using a hand spray, and a quarry tile surface contaminated with glycerol at a concentration of 90%. Contaminant was re-applied between each individual measurement. All tests were carried out in the heel test mode.

The ten samples of footwear were also tested according to the EN ISO 13287:2007 test method, on the steel surface with potable water contamination. This was to allow a comparison with the results generated according to the modified test method.

6.2 RESULTS AND DISCUSSION

6.2.1 Steel and Water

Ramp test data and mechanical friction test data for ten items of footwear tested on water-wet steel are displayed in Table 3 and plotted in Figure 8. According to the modified mechanical test, a number of samples of footwear presented a moderate slip potential, where the ramp test suggests the slip potential is actually low, and a number are presented as high, as opposed to moderate. This indicates that further modification of the test parameters may be necessary.

Table 3. CoF data for the ten footwear samples on water-wet steel (red represents a high slip potential, amber a moderate slip potential and green a low slip potential)

Footwear	HSL Ramp Test CoF	Modified Mechanical Test Mean CoF_{6-10}
Sample 1		0.47
Sample 2	0.51	0.35
Sample 3	0.41	0.33
Sample 4	0.37	0.29
Sample 5	0.34	0.22
Sample 6	0.3	0.23
Sample 7	0.27	0.25
Sample 8	0.27	0.13
Sample 9	0.15	0.13
Sample 10	0.13	0.1

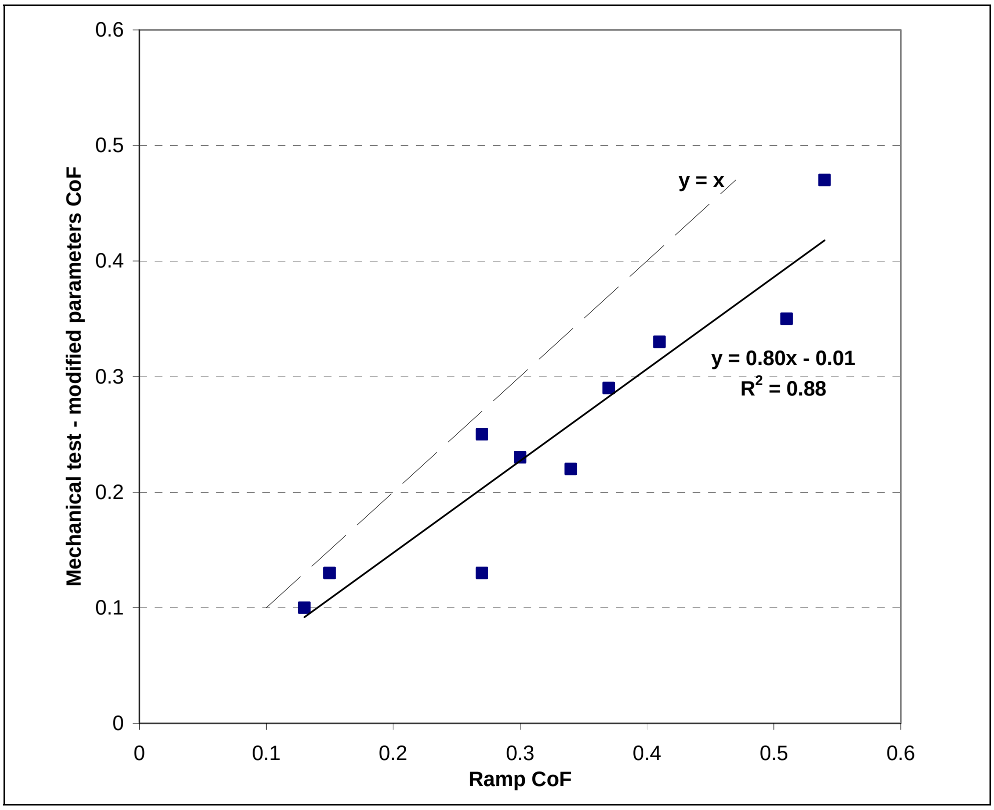

Figure 8. CoF data for the ten footwear samples on water-wet steel

The plot showing the CoF generated with the modified parameters of the mechanical friction test against the ramp test data for 10 samples of footwear (Figure 8), suggests a relationship exists between the two test methods. When compared with the results generated to the EN ISO 13287:2007 parameters (Figure 9), the modified test method shows an improvement in the agreement between the ramp test and mechanical friction test.

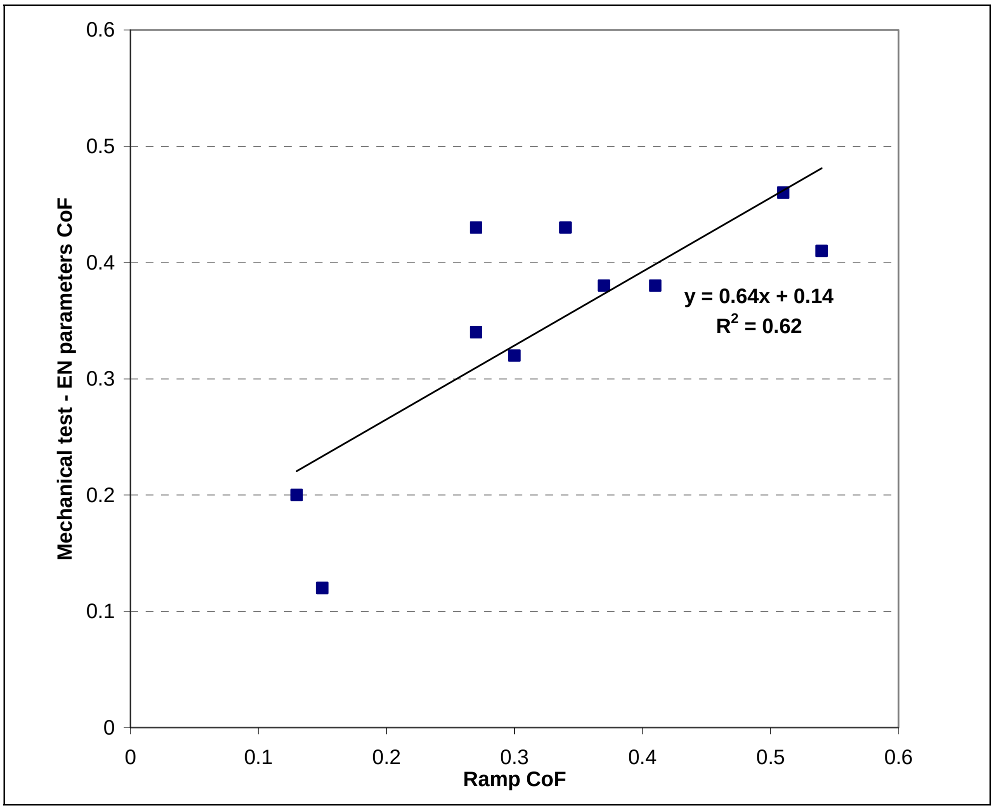

Figure 9. Mechanical friction test CoF measurements, made according to the test parameters outlined within EN ISO 13287:2007, plotted against the CoF Ramp Test Method

Modification of the mechanical test parameters has produced encouraging results for the limited number of samples tested. The gradient of the trend line indicates that the mechanical test underestimates the available friction, compared to the ramp. Therefore, further modification of the test parameters is necessary.

6.2.2 Quarry Tile and Glycerol

Table 4 and Figure 10 display ramp test data and mechanical friction test data for ten items of footwear tested on quarry tiles with glycerol contamination. According to the mechanical test, a number of samples of footwear presented a high slip potential, where the ramp test suggests the slip potential is actually moderate or low.

Table 4. CoFs for the ten footwear samples on quarry tile and glycerol (red represents a high slip potential, amber a moderate slip potential and green a low slip potential)

Footwear	HSL Ramp Test CoF	Modified Mechanical Test Mean CoF_{6-10}
Sample 1	0.4	0.24
Sample 3	0.37	0.28
Sample 2	0.34	0.23
Sample 4	0.32	0.21
Sample 5	0.26	0.13
Sample 6	0.24	0.11
Sample 8	0.2	0.09
Sample 7	0.17	0.15
Sample 10	0.11	0.05
Sample 9	0.1	0.07

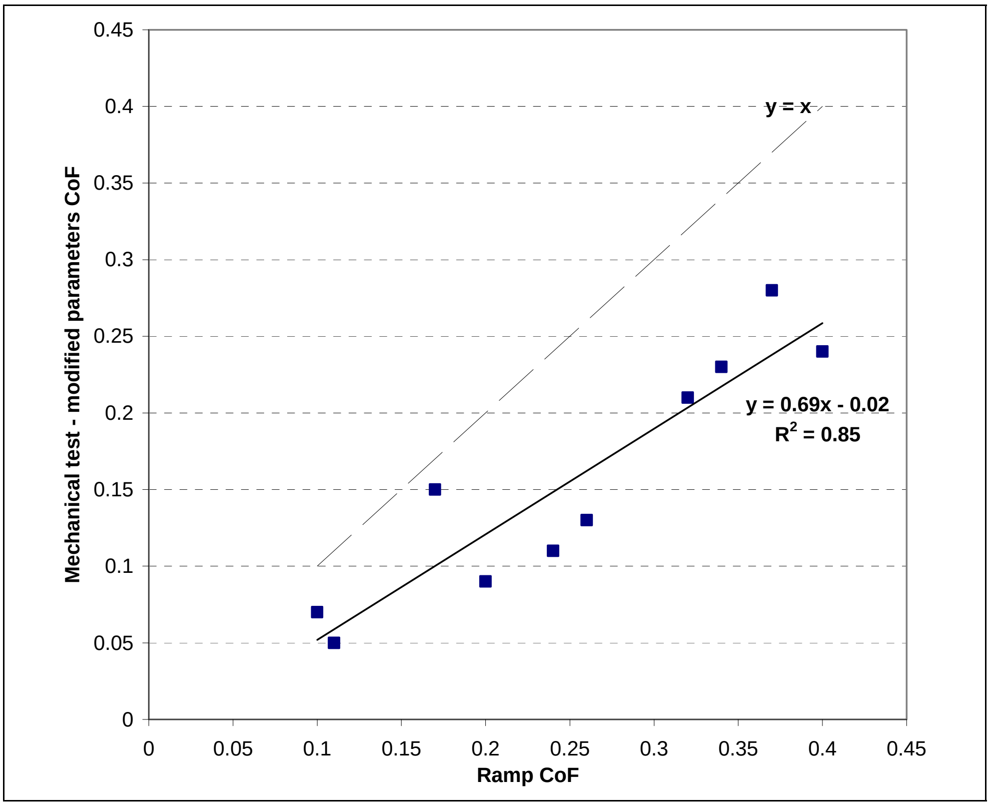

Figure 10. CoF data for the ten footwear samples on quarry tile and glycerol

Results in Figure 10 and Table 4 support the earlier findings of the steel and water tests. Figure 10 shows the similar agreement between the modified mechanical test results and those of the ramp test. The modified friction test underestimates the CoFs compared to the ramp test. This supports the earlier conclusion that further modification of the parameter(s) is required.

7 CONCLUSIONS

This study has shown that, by altering the parameters of the mechanical friction test, the data generated by the test has been brought more into line with data generated by the ramp test. The mechanical test used in European Standards tends to give higher CoF results than the HSL ramp test. The CoFs obtained from the modified mechanical test tend to be slightly underestimated although closer than the Standard test when compared with the results generated using the HSL Ramp Test under the same test conditions. Further modification of the test parameters of the mechanical friction test is therefore necessary, so that the modified test method neither underestimates nor overestimates the available slip resistance.

Modifying the parameters resulted in the following changes to the test data generated:

- For the slider 96 soled footwear the measured CoF reduced as the slip velocity of the mechanical friction test increased under the applied test conditions.

- Reducing the vertical force applied by the mechanical friction test led to a reduction in the measured CoF for the slider 96 footwear upon the water contaminated steel surface.

The result of these modifications is in line with hydrodynamic lubrication theory.

8 FURTHER WORK

This study has laid the foundations for further work. With a laboratory assessment, it has begun to address the issue of the disagreement between mechanical friction test and ramp test data. However, further modification of the test parameters of the mechanical friction test is necessary, since the modified test method currently underestimates the available slip resistance.

Developing an HSL test method for the mechanical test, which shows closer agreement with the HSL Ramp Test, will offer a more flexible method of generating slip resistance data on both footwear and flooring. This will be important for further slip resistance research for HSL and in support work for both HSE and local authority slip investigations. The results will also feed in to improving the Standard EN ISO 13287:2007 test method, within the European Standards technical committee CEN TC 161.

Further confirmation of the effects of changing the parameters of the mechanical friction test method is necessary. This can be achieved by testing a larger range of occupational footwear to the modified parameters, under different test conditions.

Investigation of the other footwear test modes (forepart and flat) could be carried out to establish if the relationship between the results generated according to the modified parameters of the mechanical friction test and the HSL Ramp Test also exists for these other modes.

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APPENDIX A

Surface Roughness Measurements

The surface roughness measurements were made in accordance with the procedure outlined within EN ISO 13287:2007. Measurements for the steel plate surface of the mechanical friction test were made periodically.

Table A1. Steel Surface: TE652 measurement 1

	1	2	3	4	5	6	7	8	9	10	Mean
Ra	0.35	0.40	0.34	0.34	0.39	0.31	0.36	0.38	0.34	0.36	0.36
Ry	3.76	3.10	3.04	2.87	3.26	2.45	3.09	3.32	3.30	2.91	3.11
Rz	2.62	2.66	2.56	2.38	2.70	2.20	2.36	2.52	2.27	2.64	2.49
Rq	0.44	0.49	0.43	0.42	0.50	0.40	0.45	0.49	0.42	0.46	0.45
Rt	3.76	3.15	3.04	2.90	3.46	2.71	3.20	3.40	3.30	2.91	3.18
Rp	0.91	1.10	0.90	1.16	1.12	0.86	1.04	1.16	1.10	1.10	1.05
Rmr	56	22	49	8	32	25	31	8	5	23	26
R3z	1.75	1.99	1.74	1.59	2	1.72	1.71	1.94	1.66	1.88	1.80
Rs	30	30	27	27	29	30	31	32	26	28	29
Rsm	-	-	-	-	-	-	-	-	-	-	

Table A2. Steel Surface: TE652 measurement 2

	1	2	3	4	5	6	7	8	9	10	Mean
Ra	0.28	0.23	0.26	0.37	0.23	0.26	0.28	0.38	0.22	0.26	0.28
Ry	2.9	2.41	3.31	3.51	2.71	2.85	2.81	4.07	2.12	3.41	3.01
Rz	2.26	1.8	2.13	2.14	1.92	2.08	2.06	2.21	1.8	2.24	2.06
Rq	0.37	0.31	0.37	0.45	0.29	0.37	0.38	0.48	0.29	0.36	0.37
Rt	3.11	2.59	3.45	3.51	2.78	2.99	2.97	4.07	2.53	3.48	3.15
Rp	0.58	0.55	0.62	0.81	0.58	0.49	0.65	0.98	0.58	0.62	0.65
	146.4	120.1	94.8	158.6	104.8	109.8	128.1	96.7	110.5	88.4	115.8
Rmr	78	68	84	30	75	85	72	11	44	87	63
R3z	-	0.96	-	-	1.04	1.07	1.37	-	0.91	1.15	1.08
Rs	46	49	73	38	39	52	41	44	49	71	50
Rsm	73	92	114	81	100	114	83	134	96	114	100

Table A3. Steel Surface: TE652 measurement 3

	1	2	3	4	5	6	7	8	9	10	Mean
Ra	0.33	0.24	0.24	0.23	0.22	0.28	0.21	0.23	0.2	0.4	0.26
Ry	2.8	2.32	3.47	2.23	4.15	3.34	2.73	2.13	1.97	3.27	2.84
Rz	2.23	1.85	2.1	1.65	2.28	2.21	1.67	1.8	1.52	2.43	1.97
Rq	0.43	0.32	0.33	0.3	0.31	0.38	0.27	0.31	0.26	0.52	0.34
Rt	2.8	2.41	3.57	2.23	4.22	3.53	2.73	2.29	1.97	3.34	2.91
Rp	0.59	0.49	0.57	0.58	0.58	0.63	0.51	0.46	0.45	0.76	0.56
	-	-	-	-	-	-	-	-	-	-	
Rmr	73	75	91	48	97	82	83	70	56	63	73.8
R3z	1.23	1.41	1.14	1.17	1.09	1.39	0.99	1.02	1	-	1.16
Rs	59	44	45	39	40	45	53	39	32	64	46
Rsm	-	-	-	-	-	-	-	-	-	-	

Table A4. Steel Surface: TE652 measurement 4

	1	2	3	4	5	6	7	8	9	10	Mean
Ra	0.26	0.18	0.24	0.26	0.24	0.32	0.24	0.24	0.31	0.23	0.25
Ry	2.97	1.74	3.88	1.97	3.01	3.69	3.59	2.42	3.52	2.06	2.89
Rz	2.19	1.5	2.36	1.79	1.89	2.59	2.24	2.05	2.49	1.63	2.07
Rq	0.35	0.24	0.34	0.33	0.32	0.43	0.32	0.32	0.42	0.3	0.34
Rt	3.09	1.76	3.9	2.08	3.01	4.19	3.59	2.42	4.05	2.32	3.04
Rp	0.52	0.4	0.55	0.57	0.62	1.06	0.55	0.54	0.77	0.51	0.61
	-	-	-	-	-	-	-	-	-	-	
Rmr	85	74	96	50	69	2	92	73	58	47	64.6
R3z	1.16	-	1.06	1.21	-	1.36	1.31	1.48	1.2	0.86	1.21
Rs	66	72	53	41	55	54	43	40	50	60	53
Rsm	-	-	-	-	-	-	-	-	-	-	

Table A5. Steel Surface: TE652 measurement 5

	1	2	3	4	5	6	7	8	9	10	Mean
Ra	0.2	0.37	0.32	0.27	0.3	0.25	0.15	0.27	0.19	0.22	0.25
Ry	2.98	3.64	2.62	2.72	2.87	2.76	1.78	3.1	2.14	3.07	2.77
Rz	2.1	2.15	2.23	2.32	2.24	2.03	1.31	2.39	1.48	1.86	2.01
Rq	0.27	0.46	0.41	0.36	0.38	0.33	0.19	0.36	0.25	0.29	0.33
Rt	3.11	3.64	2.85	3.22	3.2	2.95	1.92	3.1	2.22	3.07	2.93
Rp	0.5	0.79	0.67	0.75	0.62	0.58	0.38	0.57	0.59	0.57	0.60
	-	-	-	-	-	-	-	-	-	-	
Rmr	92	13	65	43	69	72	69	83	3	80	58
R3z	0.97	-	1.51	1.02	1.33	1.28	0.76	1.36	0.94	1.16	1.15
Rs	42	54	51	54	66	38	54	83	46	36	52
Rsm	-	-	-	-	-	-	-	-	-	-	

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A study of the effect of modifying the European Standard mechanical slip resistance test for footwear

Employers use a range of control measures to reduce the risk of slips injuries, but if a significant slip risk remains, introducing footwear with slip-resistant properties may be necessary.

The Health and Safety Laboratory (HSL) uses a human-based ramp test to assess the slip resistance of footwear. The human-based principle ensures that the parameters of a slip are closely replicated, therefore establishing confidence in the results generated. The current European Standard for footwear slip resistance is a mechanical friction test that attempts to replicate the action of a slipping foot. However, the slip resistances given by this test do not always agree with those given by the HSL ramp test for the same footwear.

This work studied the effects of modifying two parameters of the mechanical test, in order to establish closer agreement with the HSL Ramp Test. By improving this agreement, the mechanical test could be developed as a convenient alternative to the ramp test for HSL assessments of the slip resistance of footwear, both in research and slips investigations.

Modification of two parameters (slip velocity and vertical force) controlling the mechanical test in the heel slip mode resulted in improved agreement between the two tests for the limited number of samples tested. Further confirmation of the effect of optimising these parameters is necessary. Modification of further mechanical test parameters is also necessary, since the modified mechanical test currently underestimates the available slip resistance compared to the ramp test.

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